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TECHNIQUES FOR DATA HANDLING IN TACTICAL SYSTEMS. II.(U)
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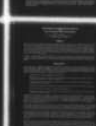
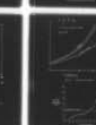
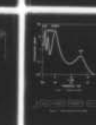
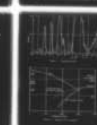
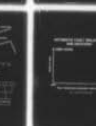
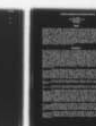
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TECHNIQUES FOR DATA HANDLING
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Copies of papers and discussion presented at the Avionics Panel Symposium held in Monterey, California, USA, 18-21 October 1978.

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THEME

Modern tactical warfare is characterized by decentralized activities of highly mobile, dispersed forces operating in an environment replete with technologically complex and sophisticated equipment. These equipments are used to acquire, transmit and process massive amounts of data so as to glean the intelligence required for the prosecution of field actions. Indeed the successful conduct of a tactical operation, the ability to coordinate the many, varied aspects of a dynamic tactical situation, depends critically on a combatants technical capability to handle data efficiently and expeditiously.

The Avionics Panel of AGARD, in recognition of the rapidly advancing state-of-the-art in data handling and the need for the dissemination of information on this subject to the NATO countries, devoted its 15th Technical Meeting in Amsterdam, Netherlands on 4-7 November 1968 to a Symposium on "Techniques for Data Handling in Tactical Systems". In the ten years since that meeting, techniques applicable to the solution of the multifaceted problems of tactical data handling have been emerging at an ever increasing rate. There have been significant advances in solid state computing devices and memories, displays, structured programming, higher order languages, operating systems, wideband communication networks, microprocessors etc. This is fortunately in consonance with and probably stimulated by the explosive growth in information requirements. Equipments based upon and incorporating these techniques have been developed and introduced into the inventory to enhance the military technical capability in this area.

The purpose of this conference is to review and present the latest developments in techniques in data handling which are applicable to the NATO tactical environment.

IRVING J. GABELMAN
Program Chairman

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CONTENTS

	Page
THEME	iii
PROGRAM AND MEETING OFFICIALS	iv
	Reference
 <u>SESSION I – OPERATIONAL REQUIREMENTS</u>	
EXPLOITING TECHNOLOGY FOR OPERATIONAL DECISIONS by I.R.Mirman	1
AVIONICS TECHNOLOGY FOR TACTICAL DATA HANDLING by E.B.Beggs	2
 <u>SESSION II – DATA ACQUISITION, DISPLAY AND CONTROL</u>	
SOME TRENDS IN DATA ACQUISITION DISPLAY AND CONTROL by J.T.Shepherd	3
THE REAL-TIME TACTICAL RECONNAISSANCE DATA HANDLING PROBLEM by H.Lapp	4
TACTICAL RADAR FOR AIR DEFENCE by R.N.Oldfield	5
IMPROVEMENTS IN THE MAN-MACHINE INTERFACE FOR DATA ACQUISITION, DISPLAY AND CONTROL by W.A.Manison	6
INTEGRATING SENSORY INFORMATION IN A MULTISENSOR-SYSTEM FOR BATTLEFIELD SURVEILLANCE by D.Paul and T.Partmann	7
TACTICAL RECONNAISSANCE IMAGE EXPLOITATION by G.L.Wycoff	8
 <u>SESSION III – COMMUNICATIONS</u>	
Paper 9 Cancelled	
THE ROLE OF ADVANCED TECHNOLOGY IN TDMA SYSTEMS by F.Amoroso and J.D.Olsen	10
MULTI-FUNCTION COMMUNICATIONS AND TACTICAL DATA LINKS by H.J.Bush	11
INTERACTION OF ANTENNA ARRAYS AND MODEMS IN TACTICAL DATA LINKS by J.O.Gobien, S.R.Robinson and E.Raska, Jr	12
A DPCM CODING TECHNIQUE FOR THE TRANSMISSION OF VIDEO SIGNALS (Abstract only) by R.Lippmann	13
BUDOS – A MULTIPLEX DATA BUS TRANSMISSION SYSTEM by S.Øderud	14
ADNET: AN EXPERIMENTAL INFORMATION DISTRIBUTION SYSTEM by T.D.Wells and M.G.Stainsby	15

SESSION IV – TACTICAL DATA PROCESSING HARDWARE**THE APPLICATION OF STRUCTURED DESIGN AND DISTRIBUTED TECHNIQUES TO AVIONICS INFORMATION PROCESSING ARCHITECTURES**

by L.A.Naglak and W.M.Norr

16

TACTICAL AUTOMATED MESSAGE PROCESSING SYSTEMS

by R.Nelson and J.Jarzembowski

17

TERMINAL DE COMMUNICATIONS TACTIQUES D'INFORMATIONS ALPHA-NUMERIQUES

par G.Joseph

18

NOUVELLES GENERATIONS DE MATERIELS TACAN

par J.C.Joguet

19

SESSION V – APPLICATIONS PROGRAMMING**DATA PROCESSING OPPORTUNITIES 1980–1990**

by A.R.Barnum

20

SOFTWARE FOR ROYAL NETHERLANDS NAVY

by J.B.F.Tasche

21

RESOURCE ANALYSIS FOR DATA-PROCESSING SOFTWARE

by E.N.Dodson

22

WORKING WITH TECHNOLOGY: DISTRIBUTED PROCESSING STANDARDS FOR THE EIGHTIES

by B.R.Gladman, K.Jackson, R.C.Makin, D.Nairn, R.S.Newton and T.D.Wells

23

PARNAS PARTITIONING

by A.J.Maher

24

HIGH ORDER LANGUAGE STANDARDIZATION

S.A.DiNitto, Jr

25

SESSION VI – TACTICAL SYSTEMS**PROJECT WAVELL**

by R.J.Fairchild

26

MOBILE TACTICAL C³ SYSTEMS

by D.Shore

27

AIRBORNE DATA TRANSFER SYSTEM (ADTS)

by C.J.Stuppi and L.W.Reed

28

Paper 29 Cancelled**PRECISION LOCATION STRIKE SYSTEM NEAR-REAL-TIME C³I FOR THE TACTICAL BATTLEFIELD**

by J.T.Bowen

30

MSI-80S, AN INTEGRATED SMALL-CRAFT FIRE CONTROL SYSTEM

by F.Å.Østern

31

JOINT TACTICAL INFORMATION DISTRIBUTION SYSTEM (JTIDS)

by C.E.Owen

32

**LES SYSTEMES DE MESURE DE DISTANCE TYPE "DME" ETAT ACTUEL
ET DEVELOPPEMENTS FUTURS**

par M.Schilliger

33

TACTICAL INFORMATION EXCHANGE SYSTEM

by J.Bonanno

34

EXPLOITING TECHNOLOGY FOR OPERATIONAL DECISIONS

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SUMMARY

The challenge is to harness the new technology by conscious exploitation and focus on dramatically improving tactical systems. The past decade has seen an explosive growth of technology; data is available by the pound, but the man-in-the-loop is unable to take advantage of the volume and spectrum of the data. Technology growth has not been matched by a growth in science of command and control. It is time to shift attention from technology which is spewing out volumes of data, and look at the decision maker's problem. His needs need to be the beginning; technology needs to be a means to that end, not an end in itself. Sharp focus is needed on the transition of command and control from a folk-lore - undefined art - to one that is based on science. Major attention is needed in providing snapshot situation assessment; decision options coupled with consequences; closed-loop decision oriented information systems with positive feed-back and a dedicated drive to conceive and develop science of command and control. One needs to think systems not techniques, decisions not data.

INTRODUCTION

This paper is addressed to the needs of the tactical decision maker, and to that end, rather than discuss technology per se, the needs of the C² decision maker are addressed. The notion that C² is a closed-looped, servo-like system with appropriate feed-back is introduced. Past problems have, to a large degree, been driven by acquisition of hardware prior to evolving a C² process needed to achieve adequate opportunity to perform both the command and the control function. Additionally, the notion that C² is heavily communications oriented have resulted in a huge input of data, not necessarily information. Little attention has been given to the orderly process needed; defining of information needed to achieve a given decision. While information theory dates back to 40's, management of information, particularly text, has not developed to improve either command or control. The dynamic threat demands fast decisions, and a new means must be provided to selectively develop information from the high volume of data, and provide the decision maker with options and associated consequences. A number of suggestions are made that merit additional work.

1. With this symposium dedicated to technology for data handling, one should recognize the explosive growth of technology, micro-circuits, micro-computers and signal processing, and the new doors it has opened in terms of detection, control and weaponry. We are at the beginning of a new era - abundant technology. The dramatic explosion in technology will have a marked and even unpredictable impact on the future. In retrospect though, it is mind-boggling to realize that a room-sized computer of a decade ago is now sized to hold in your hand. I am sure that the fine papers in the next few days by technology experts will cover these exciting advances.
2. I will instead discuss technology as a means to an end. An end, which is expressed in terms of the military need for command and control systems which are responsive, closed-looped and adaptive.
3. The explosive technology growth unfortunately has not been matched by a comparable growth in its use, nor in the science of command and control as it applies to military needs.
4. In the past decade or more, because of the opportunities offered by new technology, there has been a tendency for us to introduce new boxes which, by themselves, offered tremendous improvement to a function over the past. Yet there has been a lack of cohesion in the use of these boxes in satisfying an overall system need. As a result, we tend to build command and control systems from the bottom up by selecting the boxes and trying to find use for these in an operational system. This has been encouraged to a large degree not only by the exciting opportunities that technology offered, but the fact that these boxes were tangible definitive end-products. Whereas effective use of these boxes resulted in systems often hard to define or visualize as a precursor to the acquisition of these boxes - this results in the "box syndrome".
5. It reminds one, to use an analogy, of a composer of music such as the deaf Beethoven, who wrote symphonies and carefully evolved a set of data and notes on how the various instruments he visualized best contributed to the music (or score) he had composed. The conductors who play this music select the instruments as the composer prescribed, but the skill of the conductor is keyed to his success in achieving the intent of the composer's score (MIRMAN, I.R., 1974).
6. In contrast, in command and control systems, in the past we tended to select the "instruments" first, and then tried to compose the "score" afterwards. The operator is often given a set of equipment and is on his own to evolve the best way to utilize it (MIRMAN, I.R. 1974). Today we do it iteratively with the operator as a partner, nevertheless evolving the process is difficult.

7. From the military point of view, command and control systems are the wherewithal in support of military action. War, in the final analysis, concerns itself with two segments of activity; communication of information and the delivery of energy.
8. This paper will focus on only one of these two segments: communication of information (COI), with the objective of the use of that information to the effective delivery and use of that energy. Implicitly then, one needs to examine information needs of a decision maker who must decide if, how, when and where to utilize his forces.
9. The growth of communication technology has been such that data rates have increased well beyond man's ability to absorb them, and while there is no doubt that new technologies on the horizon will increase these data rates by orders of magnitude, we have yet to focus on the human's ability to take full advantage of this form of data.
10. Unlike that nation in the Middle East that selects its military personnel as a function of the size of shoes they have available in stock, we need to find a way of tailoring our technological products to satisfy the man rather than vice versa.
11. Ideally, a closed-loop command signal system, which consists of a series of L networks; one for data; information decision and execution, with feed-back control to achieve a stable, critically coupled servo-like system, is needed. However, the input to the system is far from ideal; it is conditioned by noise, since it is usually data and information which range from fact to rumour, poor intelligence, biased information, etc. The noise in the loop which represents information of unknown quality, could be reduced by subjective judgement of the decision maker. Key in this loop, of course, is the decision maker himself, and a way needs to be found of extracting the information content of a massive set of data and presenting it in palatable form. The subjective judgement he exercises is a function of experience, training, and what is a difficult to define factor that is best called "intuitive response".
12. The feed-back factors that control the stability of the servo-like command and control system are not easily quantified, but can best be identified by at least three possible factors if one considers the closed-loop system to consist of 3 L networks in series; β_1 being the feed-back after data has been converted to information; β_2 being the feed-back that couples the decision maker to the information source and is effectively driven by "intuitive response"; β_3 being the feed-back on result of execution of a decision and, in effect, the major contributor to the "control" function of the system. In the real world, however, β_1 is over-coupled with excess information; β_2 and β_3 are usually under-coupled, and as a result system stability is difficult to achieve.
13. The intuitive response part of β_2 is obviously personality sensitive, hence the system must be capable of coupling effectively to a particular decision maker (DM), and have flexibility to perform, when other decision makers take over. Unfortunately, in the past our systems were often designed to meet the original decision maker's requirements and were generally delivered some seven or more years later when a new decision maker is the recipient of the system. Recognizing every individual has a finite information capacity, and unique intuitive response, systems in the past may not have been flexible enough to accommodate the change.
14. In any given country, commanders rise to their position as a result of a spectrum of experience, culture, language, training, tactics; all are conditioned by their national policies, doctrines and inter-service relationships, and all have developed their own management strategies and intuitive responses. Immerse this conditioned commander and his staff in a NATO environment and he is faced with a series of unanticipated problems, particularly in command and control. Communications under such conditions are seriously affected, as well as his information requirements. In some instances, basic procedures of command may differ. For example, one national view might be to command the taking of Target 'X' by simply saying it, whereas another, for the same objective, could prepare a multi-page, detailed message on taking Target 'X', along with instructions of constraints and rendezvous, and logistic support, reporting sequences and procedures, leaving little initiative to the commander. This, of course, imposes severe stress on C^2 systems, that challenges system designers. Though problems of this nature are solved, they have been brute-force solutions that need refinement, particularly in stress situations that are time-sensitive.
15. Efforts to anticipate this problem have been in the form of providing excess data. Indeed, new technology available encouraged this flood by virtue of high speed circuits with printers now exceeding 3000 lines/minute, but since humans can only read in the order of 30 lines/minute, one minutes worth of messages take one man 100 minutes to read - of course, if time is critical, one needs more people. And with this, a chain of reactions occurs. Since this volume of people (M) need to coordinate and interact the $2^{M(M-1)}$ law takes over, resulting in interactions which are effectively a function of $M^2/2$ (WIEKHORST, F., 1977). These interactions could delay rather than speed up the information flow. This then, dictates a need to consider limiting manpower, and seeking technical solutions to the flood of information and its management as well as ensuring we satisfy the need for "intuitive" information.
16. Everyone has his own notion as to what a C^2 system is, or is not. Like the study by British Transport Authority on bus schedules which resulted in a finding that stated schedules could be met - if they did not stop to pick up passengers (RYAN, P., 1977). We may have forgotten the prime purpose of the system. In the case of C^2 , it is to satisfy a single commander at a given echelon. C^2 is intangible because it is "a process" that knits men, equipment and commander together.

17. To this end then, it might be best for us to examine the needs of this commander in terms of its impact on communication of information.

18. In discussions with commanders you find that they do not think in terms of any elaborate concepts, but rather stress the essential needs of new and changed information and having ability to discuss options and opinions.

19. Characteristically, each commander has his own personal view obviously conditioned by his culture, training and intuition, and surely as a commander, he must be a realist.

20. Chess has been cited as a game, but in fact von Neumann viewed it as "a well-defined form of computation". Now real games are not like that at all. Real life consists of bluffing, tactics of deception, and asking what the other man is going to think I mean to do. Real games do not have precise solutions that chess has (BRONOWSKI, J., 1973). In this sense then, the decision maker needs information to permit him to determine what his opponent perceives - to permit him to exercise his intuitive judgement, based on what odds he thinks exist, in his gamble.

21. Of course, the decision maker's decision is a command, but a responsive system is needed to provide a capability to implement and control that decision. In essence then, one must put in perspective a total C² system rather than discrete information per se in a given environment. Given information on enemy intentions and perceptions, the decision maker must be capable of defining targets, developing strategy and effectively employ his force.

22. Hence, we must find ways of providing him with options along with consequences, to aid in the decision process. The notion of developing response algorithms that provide sets of weighted options and their respective consequences appears possible and needs attention.

23. From the commander's point of view, C² must aid him in controlling his force, avoiding errors and achieving his objectives. From the technical point of view we need to relate these to his information needs.

24. Implicit in the commander's needs is being able to operate and survive in hostile environments; his information needs are many: (WELCH, J.A., 1978)

- (a) Information that would dictate deployment on short notice.
- (b) Ability to operate and survive in a variety of conflicts.
- (c) Anticipate what his enemy perceives and gambles based on information of enemy intentions, and current and projected information of enemy location.
- (d) Anticipate surprise.
- (e) Avoid suspense.
- (f) Needs to have high confidence in enemy identification.
- (g) Needs sufficient information to target his weapons against selected targets and rapid assessment of information on results.
- (h) Needs information on real-time basis, with confidence on posture and currency of his own forces.
- (i) Needs information that keeps him constantly aware of actions he has directed and their results - this feed-back is an essential and a system-confidence-factor that he is very dependent on.
- (j) Finally, he needs information and identification capability to avoid using his weaponry against friendly forces by mistake.

25. To add to his problems a senior NATO commander is beset with political constraints which impose a heavy information demand on system and particularly effects communications. These can influence his decisions at various stages of conflict, for example in force deployment, reinforcement, and weapon use.

26. Immersion of this commander and his staff in a NATO environment adds additional dimensions. One is language - while one can talk in other languages, and in NATO there are eleven (11), the problem of comprehending the intent, particularly in combat stress environment, in someone-else's language is difficult (HAIG, A.M., 1978). In stress situations one tends to resort to one's own language, where you can say what you mean, which can range in style from educated to gutter style. Hence, in combat situations where multi-national communication is essential, difficulties could arise. In situations where confidence of decisions is frequently influenced by one's verbal statements as to intent and inflection, language and comprehension becomes an important factor. Hence, the likelihood of situations without conversation, particularly at high commander level, is unlikely in future. However, in lower level combat situations, technical means of overcoming the language barrier needs major attention. Of course, digital message entry devices using a priori formed messages is one possible solution.

27. Another dimension is coordination between air/ground - this is not unique to NATO, but what does add an element of uncertainty is that organizations and relationships between air/ground forces differ, though procedures and extensive training have resolved these differences. However, this area obviously has a significant impact on data, and information, and the amount of communication needed.

28. The equipment sub-systems in C^2 involve, of course, sensors, communications, data processing systems and their associated logistic support. In the context of the last decade, the commander in a tactical force is now faced with an additional dimension, namely that of survivability in an environment now threatened by new technology and weapons systems. This dictates the vulnerability of fixed tactical installations. As a result, continuous movement becomes essential and, moreover, the vehicles per se must not only be concealable, but have low energy radiation to avoid detection by new technology sensors. Normalizing heat distribution from a detector point-of-view dictates examination of vehicle size and its components including people. The battlefield may well become untenable for all but the most agile and best concealed.

29. The great need for mobility in view of technology threats suggests common-sized vehicles, and netting information on its own dispersed forces creates major communications problems in the context of supporting the C^2 process for the decision making functions. Maintaining cohesion of forces, particularly during enemy attack, demands a need for self-sufficiency of segments of his mobile force so that graceful degradation is possible. While mobility fragments the operation physically, we are challenged to knit it together electronically and keep the commander in control of his force.

30. New technological weapon systems and sensors have now made it possible to conduct combat at night, and in Europe the poor weather conditions provide convenient cover. If one is considering surprise, the likelihood of attacks in this time period is high. This drives the need then for systems which provide for operations under these conditions and cohesion of the force becomes a critical element. Under these conditions, the commander needs real-time information of his own as well as enemy forces; and to avoid suspense and surprise needs information that literally permits him to "see at night"; this night problem drives the need for critical information C^2 systems.

31. The dynamic changes of technology are not a challenge to the operational commander since his weapon systems reflect production state of art, and are what they are. Accordingly, it becomes imperative that the system designers provide increased flexibility so that the commander's options can be supported in an environment where the threat and advantages of changing technology are on the enemy's side.

32. Message transmission is getting a "package of data" to the right place at the right time; the contents of package, on receipt, need to be assessed as to "value" and intent and a decision made as to its information content. The latter is an undefined area that "begs" for new ways of deriving information for the decision process. The tendency to increase bandwidth and channel capacity encouraged by the high data rate, needs to be examined more carefully since it provides license for longer messages which increase the potential for blunders. Use of written type messages to convey information have limitations even when the recipient is in a clean, comfortable noise-free environment, but immerse this message in a condition of crisis, coupled with a drastic change in environment, such as arena of combat, and the reader could turn primitive. In many cases messages will be misunderstood, long messages not read, and at worst not even reach the commander.

33. It is clear then, that information per se, is fundamentally an essential element of the commander's needs. However, what needs to be recognized is that the commander does not require data per se, though equipment sub-systems like data processors for radars, weapons etc., do. He gets data by the ton at this point because of our ability to have high data rate messages. What he badly needs is information that is fresh, that shows a change, that tells him something he did not know before, or confirms previous known information. He also needs a continuum of information on the results of actions he has directed previously, i.e. the β_3 term I mentioned above. He cannot be under suspense or be surprised. Director Alfred Hitchcock once said "suspense is a matter of knowledge. If a bomb unexpectedly goes off in a movie - that's a surprise. But if the audience knows a bomb will go off in 5 minutes, and the hero on-screen does not, that's suspense".

34. Wiener and Shannon postulated that a message, as well as interfering noise, could properly be described only in 'probabilistic' terms. This formed the basis of information theory back in the 40's. Criteria of acceptability of the message on the part of the users is not an 'isolated event' but a coupled one between the source and the user. The coupling, in effect, transforms data to information. Shannon essentially showed that change in probability of a message or event is an indication of information. Information then, by definition, is well defined, is relevant and timely, and is in terms of probability.

35. While Shannon's theorem has been well exploited in the coding and communications systems that achieve error free streams of words, we have yet to fully exploit his well-defined theory on 'information', to provide selected text messages/statements of information in terms of their intent or meaning to meet the commander's objective, and avoid surprises.

36. In this past decade, the speed of weapon systems has increased and the responses and reaction time has become time critical. In turn, need exists for having higher speed processing of data and information to decision maker. However, the resulting flood of data dictates the need for the insertion of active filter processes that will convert the data to information classified by message content/intent that has high probability of interest. This is now a major manpower "chore".

37. We have attempted to solve this problem by increasing manpower. However, since the $M^2/2$ law takes over, the large masses of manpower could be counter-productive since they could begin to communicate with themselves and lose sight of the filtering objective. Evidence of this is seen in software development efforts.

38. Nature has resolved this problem by design of a nerve system that eliminates extraneous data and only allows information to pass. This technology is perfected, but we do not know how it works - and we all have this facility. The synapse terminal at each nerve ending is this ideal filter - it rejects all signals, except those whose information is intended for that action (WIEKHORST, F., 1977). Our challenge is to duplicate this capability in C² system.

39. The availability of ADP has made it possible to store heavy volumes of data. Of course, data can be stored forever, but since information is time sensitive, one can have lots of data without information. Obsolete or untimely data becomes a log jam, and if it continues to be ignored, challenges credibility of current data. A means must be created of disposing of useless information and this requires major attention. Moreover, information that is not tagged in some way to show its currency or age may be useless to a decision maker who, having doubts about its currency, tends to lose confidence on use of such systems.

40. Key to a commander's needs is having relevant information in a timely manner, and support his intuitive responses in less time than an opponent can react. More information is not always better than less, no matter how little we have, and how bad things are, there is always a best thing to do (WELCH, J.A., 1978).

41. Use of information derived, needs to be conveyed in snapshot format; there is a notion that large-scale displays are key elements of C² - this notion could be so - if such displays could contain information; for example, a snapshot of his own force, the enemy, the environment, the delta change over time, etc. However, while the technology of creating and projecting large scale displays has advanced dramatically, the science of the best ways to convert data to information, with its associated probability in a given environmental situation and display it, has not. We need to devise new methods of getting the best out of ourselves. Written text derived from the lesser capacities of the human ear which required slow sequential method in which one word followed another. But a map, was an example of how a great deal of information could be passed to the brain in much shorter time by use of the eye. The development of technology makes possible generation of diagrams in a way comparable to use of maps. A major question is how much information is needed to make the presentation of a scene as effective as if the perceiver were actually there (BONDI, Sir Hermann, 1978).

42. It is an old adage that a picture is worth 1000 words - yet we have still to develop a satisfactory means to convey to the commander a meaningful picture of a situation. Brute force of video transmission to ground on one hand is easy to do, but its value is far from solving the basic problem. It is another instance of raw data that needs filtering to determine information content. Use of colour has not been effectively utilized to denote items of command interest proportional to its importance. Real-time display of information, needs no new display technology, but we need recognition of a need for coupling between the information display and the commander's eyes to take full advantage of that little used sensor to the brain of the commander. This area could be extremely fruitful and represents a major technical challenge.

CONCLUSION

In conclusion, it is time that we shift attention to the decision maker's plight in C² - his needs need to be the starting point. This is not only an opportunity, but indeed a great challenge. We need to consciously select and adapt our abundant technology by thinking "systems not techniques"; thinking "decisions not data". The C² decision maker's problem of communications of information is key to improving effectiveness in operational performance of tactical systems.

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DISCUSSION

A. Clearwaters

You have spoken mostly about the man/machine interface in terms of machine to man, what about the other direction?

Author's Reply

Once the class of information needs are established, implementing it in the machine should not be too difficult.

There is no technology problem, what it does require is innovation and adaptive techniques to improve the interface such that the Beta term of the feed-back loop permits a stable closed-loop decision system.

D. Bosman

In view of the enormous amount of data which a system can provide to the operator; and knowing that the decision capability of the operator is constrained by his central nervous system which processes about 10 bits per second, do you recommend the design and use of a general type of preprocessor or conditioner?

Author's Reply

Your point recognises the limitations of the decision maker as a human. While I recognise that his nervous system is limited to 10 bits per second – I understand this is the output-execution rate – I'm not sure I know the data rate of conversion of data acquired by the eye/ear to the brain. I am convinced that the eye has a much better capability than in merely reacting to a written word. Your recommendation of providing preprocessors or conditioners would permit the digestion of the huge volume of data, conversion to information and conditioning of this information such that it could be displayed not in tabular or written form but rather in picture or snapshot form that effectively conveys the information to the human. It is indeed a worthwhile approach that I would encourage.

D. Bosman

Do you recommend research into general type of tools for the systems designer so that the user will be able to fully exploit the system's capabilities as applied to his particular process (*a posteriori* activity allocation and design).

Author's Reply

Since an effective system is one that satisfies the personality-driven needs of a decision maker, there should be a class of generic sets of information needs that are inputs to his decision mechanism, including his intuitive response. Research into types of information needed for military decisions would certainly be worthwhile. Some studies in UK in role-playing scenarios have indicated that intuitive response plays a large role in the decision. Modelling of the process is difficult since experience over the past 20 years indicates that 45% of crisis that occur are usually surprise type category. Logically, *a posteriori* analysis would be desirable, and could be effective – unfortunately obtaining sufficient data after the fact has been difficult because in the real world recorded data on the flow of events usually does not exist. However exercises such as those like Able Archer and others in NATO do indeed provide such an opportunity and in these cases, data is being acquired to a limited degree.

I am firmly convinced that the best tool for the designers is the decision-maker himself. Proposals to satisfy the user in the form of a set of experiments in which the user actively uses and evaluates, followed by interactively improved experiments until the user is satisfied is a most effective approach.

AVIONICS TECHNOLOGY FOR TACTICAL DATA HANDLING

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SUMMARY

This paper addresses the trends emerging in Naval Aviation and their impact on the avionics community. New avionics concepts are discussed with emphasis on the technical and managerial challenges which must be met to assure their successful implementation. These challenges include the software implementation of distributed network control and fault tolerance; NATO interoperability and standards; and logistic support.

1. INTRODUCTION

The avionics concepts presented in this paper are to satisfy the ever growing needs for greater quantities of on-board information to be available within a shorter time frame. Concurrently, the trend toward smaller dispersed aircraft means that less weight, volume, cooling, and prime power will be available to support these improved performance systems. Clearly, a "brute force" approach to achieve the required performance levels will not work. We must use all available resources at all levels more efficiently: interoperability of all NATO forces, cooperative tactics between platforms, multisensor correlation, complex waveforms, improved signal processing, and automated decision aids.

1.1 THREAT TRENDS

Over the last decade, there has been a substantial strengthening of the Warsaw Pact capability to launch a major attack on Western Europe. Such an attack might occur after a period of mobilization and deployment, or the forces already positioned in Eastern Europe could attack without reinforcement, and with little tactical warning in the midst of a major East-West crisis.

Naval Aviation forces participating in the defense of Western Europe must face increased quantities and types of enemy forces, significantly improved air defense systems, and sophisticated electronic warfare capabilities. These combined factors will make the Navy power projection mission more difficult than ever before.

Similarly, the threats to the sea control mission are significantly increasing. There are more hostile platform types operating at far greater ranges. At the same time, there is an increased dependence on the "sea lines of communication" for the supply of energy and other raw materials.

1.2 DEFENSE TRENDS

In order to counter these threat trends within the financial constraints of a peacetime economic climate, President Carter and Secretary Brown have made major initiatives toward achieving a greater integration of NATO doctrine, tactics, procedures, equipment and logistics support. At the Department of Defense level, this policy is called "RSI", which stands for rationalization, standardization, and interoperability. For the research and development community, the implementation of this policy will mean increased emphasis on improved interoperable command, control and communications systems as the keystone for enabling cooperative tactics to be employed. There will be an increase in cooperative development programs to reduce unnecessary duplication of defense research efforts. Considerable emphasis is being placed on the development of effective equipment and data format standards which will facilitate both interoperability and logistic support.

Within the Navy, the trend is toward dispersing its aviation capability at sea through the development of aircraft capable of operating from ships other than a conventional aircraft carrier. Although this approach has high operational payoff potential by increasing the area covered by our forces and decreasing their vulnerability to a concentrated attack, it will require significant changes in the way we build aircraft.

1.3 AVIONICS IMPLICATIONS

These trends will have major implications for avionics developers. We will have to find ways of providing better performance with less of almost everything: weight, volume, power, cooling, and dollars.

Currently, the range of some of our airborne weapons exceeds the effective range of the radars which control them. If we are to strike within heavily defended airspace, we will need improvements in detection range and accuracy, identification techniques, and in addition, low probability of interception (LPI). Communications links must have greater capacities, be secure, jam resistant, and have LPI. The tactical data handling systems will be required to process greater volumes of data and perform a variety of new tasks designed to make the aircrews job easier, such as multisensor correlation, threat recognition, and other automated decision aids.

In addition to those areas where direct performance increases are needed, major emphasis

will be placed on improving the efficiency with which we perform existing functions. Digital technology permits us to use complex waveforms to reduce power requirements and perform multiple functions. Digital controls will be employed throughout the aircraft. Not only is the control system itself lighter, the fact that it can be operated under computer supervision allows concepts of resource sharing and fault tolerance to be implemented. Improved tactical data handling and communications capabilities can offer the platform designer even greater potential weight savings if the cockpit workload can be diminished enough to reduce the number of crew members. This could be accomplished either through on-board automation or by processing the information remotely using data links.

Another major way that force dispersion concepts affect avionics is that many of our aircraft will no longer have access to the extensive maintenance capability of an aircraft carrier. The entire avionics maintenance and support philosophy will have to be changed to enable these systems to be maintained without extensive ground support equipment. For future avionics systems, we must develop the maintenance concepts concurrently with the hardware. While it has long been an objective to plan for the total life cycle of a system the new maintenance concepts must reach to virtually all levels of the design process. Considerable emphasis will be placed on the use of built in test equipment and computer diagnostics to isolate faults. The development of appropriate hardware standards will be required to reduce the number and types of spares to manageable proportions so that they can be carried on smaller ships.

2. ADVANCED AVIONICS CONCEPTS

The common characteristic of virtually all of our avionics technology programs is that they involve extensive use of digital technology. To achieve better integration of all information available on the aircraft and better utilization of all hardware resources, subsystems on tomorrow's aircraft will be interconnected to a greater degree than ever before. Various estimates obtained from aircraft and avionics companies have indicated that the next generation of Navy Airborne Early Warning and Antisubmarine Warfare aircraft will use nearly two hundred microprocessors distributed throughout virtually every on-board electronic/electrical subsystem. At this series of briefings you will hear detailed descriptions of three of our key programs in tactical data handling:

Joint Tactical Information Distribution System (JTIDS)
Tactical Information Exchange System (TIES)
Avionics Processing Architectures

JTIDS is a joint service program to provide digital Integrated Communications Navigation and Identification (ICNI) services for a wide variety of tactical elements.

TIES represents an advanced on-board architecture for satisfying aircraft communication, navigation and identification requirements. The major difference in the TIES approach is that the hardware employed is general purpose, programmable hardware that can be reconfigured to meet mission needs or to reroute around failed components.

The exploratory development work in avionics information processing architectures will form the framework for integrating the various components of tactical data handling into an avionics system. In order to take fullest advantage of the flexibility of digital electronics, the system design should be developed from the top down, or from general requirements to the specific hardware and software implementations. The primary intent of this effort is to develop a formally structured methodology for the definition of processing architectures.

3. SYSTEM DESIGN ISSUES

Most of the challenges faced by the developers of tomorrow's avionics systems will be at the systems and managerial level. We have an overabundance of digital technology. We need to learn how to use the available technology effectively and this includes not only building an avionics system that performs well, but also one that can be supported and will work with other platforms. To accomplish this will require strategies which can control hardware and software proliferation without unnecessarily inhibiting the introduction of new technology.

The use of programmable digital hardware frees the system designer from the traditional fixed subsystem organization of avionics "black boxes". How the avionics system functions are allocated among hardware, software, and firmware can be determined by a variety of design criteria and constraints. A large portion of the functional organization of the avionics system will exist only in software. Many of the hardware resources will perform multiple functions under software control. This will enable implementation of advanced system concepts through the use of multisensor information correlation, hardware resource sharing, and automatic fault tolerance and recovery techniques.

Not only will much of the system organization be defined in software; the organizational structure can be dynamic, changing in response to events such as hardware failures, mission needs, or processing loads. While it seems to be generally agreed that future avionics information handling systems will be "distributed", there is not a consensus on what it is that will be distributed: hardware, software, processing, data bases, control, or some combination thereof.

Although these systems offer exciting potential for overcoming the limitations of conven-

tional hardware systems and improving the utilization of available information, they are not without risk. To accomplish these objectives will require some degree of centralized control, regardless of whether the system is defined as distributed, federated, or hierarchical. Interspersed throughout many publications concerning distributed processing systems for avionics are seemingly innocuous statements that executives and operating systems have not been developed before for large scale distributed systems, and that the design of real time executives remains more of an art than a science.

As a result of the tremendous technological advances in microelectronics, avionics designers now have the opportunity to consider system concepts formerly feasible only for land or sea based systems. Large scale integration of electronic circuits has now enabled equivalent processing capabilities to be implemented within aircraft weight and volume constraints. Many of the advantages being promised for future distributed avionics systems parallel those made for the large scale multiprocessing systems of the mid 1960's. Among these are: "modular system growth", "fault tolerance", and "sharing system-wide resources".

Many of these early systems failed to live up to the promises made for them in cost, time, or performance. One of the most common causes of failure was the specification of a hardware system that had the flexibility and expandability to handle any potential requirements, leaving the software design until later.

From a manager's viewpoint, there are sound historic reasons for following a moderate course toward the introduction of these systems. The Navy's approach to development of distributed avionics utilizes a structured "top-down" design process that considers systems requirements as a package and develops the hardware and software designs concurrently. The objectives are similar to those of structured programming but with wider applications. A major goal is simplicity. The availability of small inexpensive processing and memory elements allows them to be utilized less efficiently in order to make the system design less complex. We are rejecting some of the more exotic hardware configurations requiring a complex, and as yet undeveloped software system in favor of a more straightforward approach in order to avoid many of the problems experienced with prior system developments. A few illustrations of lessons learned in the development of ground based systems will illustrate the reason for this concern.

3.1 THROUGHPUT

The real value of a tactical data handling system is not measured in bits/microsecond; it is measured in number of targets identified, weapons controlled, measures countered, etc. When processors are interconnected and working on a common problem their throughput will be somewhat less than the product of the number of processor modules and the throughput of each processor unless the processes are independent, or nearly so. This is a condition seldom found in command and control applications.

When the concept of multiprocessing was new, the system block diagram would illustrate a number of processors with additional processing elements shown by dotted lines, indicating the processors could be added as needed to meet expanded processing requirements. Unfortunately, the additional processing capacity was often dissipated in "overhead" activities.

Figure 1 illustrates the results of a relatively simple simulation of the solution of a set of simultaneous linear equations for an electrical network problem by a number of processors. The figure shows clearly that as the number of processors is increased, the incremental processing gain from each additional processor becomes smaller and smaller. In the case where there are only two equations to be solved, additional processors begin to get in each others way and actually degrade system performance.

The above example was a simulation of the time required to solve a set of static equations by a number of processors, not a large real time command and control system. Figure 2, however, is the system diagram of a major command and control system developed in the mid sixties. Note the similarity between this diagram and those shown for planned integrated avionics systems. The major difference is the physical size of the modules.

The full scale development of this system had been underway for over two years. The hardware had been delivered, the software specifications written, and the subprogram and data base design completed. Over one hundred programmers were generating code. At this point, sufficient information was available to prepare an event simulation of the system.

New estimates for the anticipated system loads and operating time were prepared that indicated that five (5) seconds/second of operating time would be required, considerably more than the original estimates. Theoretically, one (1) second/second of operating time is available from each processor. When the event simulation of the proposed system configuration using three (3) processors was conducted, the maximum available operating time was approximately 2.5 seconds/second, half of that required. The remainder of the three (3) seconds/second was used up internally due to resource competition and "overhead" functions. More importantly, additional simulations indicated that when more processors were added to the system in an attempt to meet the increased processing requirements, the available operating time actually decreased. These findings showed the claims for a "modular system growth" could not be realized in practice.

More processors could be added, but no increase in the amount of useful work performed would result. The only solution was to make several major modifications to the executive

program, data base, and several of the key subprograms in order to provide real time operation of the system. At this point in the full scale development, these changes had a major impact on cost and schedule.

3.2 FAULT TOLERANCE

The system illustrated in Figure 2 was also intended to have automatic fault isolation and recovery to provide an overall mean up time of 20,000 hours. This was to be achieved by providing one spare of each module type. When a module failed, the system would automatically isolate the failed module, reconfigure the system using the spare module and alert a maintenance technician. Hopefully, the failed module would be repaired and be placed on standby before another module of the same type failed. Then the mean time between failure and the mean time to repair for each module were plugged into standard reliability equations, it was found that the expected operating time before a failure occurred without a spare module available was in excess of 22,000 hours, well within the specification. However, some module in the system can be expected to fail about every sixty (60) hours. If there were no automatic fault isolation and recovery, this would be the system up time.

These calculations, however, ignored the mechanisms for error detection, fault isolation, and system reconfiguration. Whenever a fault is detected, all processing is suspended, the contents of the data and error registers are logged out, and the software begins to isolate the error. When the faulty module is isolated, and error history table is consulted to determine whether the error detected may be a transient error, or whether the module has experienced a hard failure. The system is then either restarted or reconfigured and then restarted, and processing is resumed. The entire process was expected to take approximately twenty-five (25) milliseconds. Thus, the system could be expected to run without a major interruption for more than 22,000 hours, pausing only every sixty (60) hours or so for twenty-five (25) milliseconds to "heal" itself.

This can only happen if the fault isolation and recovery works perfectly each and every time. The curve shown in Figure 3 illustrates the dramatic drop in system up time that occurs when automatic fault isolation and recovery is only slightly less than 100% effective. At 99%, the system mean up time has dropped from more than 22,000 hours to less than 5000 hours.

The key point here is that the total system reliability hinges on the reliability of the fault isolation and recovery mechanism which is unknown. It is virtually impossible to analytically assess the correctness of a software package; there are too many paths to check out individually, even with a computer; and a common rule of thumb states that only about one half of software errors are discovered prior to operational deployment.

Most of the discussions concerning fault tolerance center around the ability to reconfigure around failed hardware. This must imply at least some sort of central control. Since software has not been perfected and probably never will be, we cannot afford to build systems, especially those involving flight critical functions, under the assumption that the software will work as anticipated. We must be sure to address fault tolerance of the software itself, particularly in critical areas involving system control. The software must be tolerant of internal faults as well as faults in the error detection logic. While some form of central control is required, provision must be made to prevent a minor "glitch" from causing a system crash.

4. ACQUISITION AND SUPPORT ISSUES

The performance of an integrated avionics system is not the only criterion for success. The system must be compatible with other systems to achieve interoperability. It must be supportable and maintainable, and there must be an effective transfer of the technology from the research and development community to the acquisition community. These issues are at least as complex as the pure technical issues since they involve not only the technical considerations, but legal, political, and economic considerations as well.

4.1 TECHNOLOGY TRANSFER

Integrated digital avionics systems will pose new challenges for technology transfer. In theory, digital technology should be easier to transfer from the laboratory environment to a prime contractor. Digital hardware should be more easily integrated (assuming that the interfaces and formats have been standardized) with less "peaking and tweaking" than analog circuits. Much of the technology to be transferred is in the form of system concepts and software which can be directly transferred if our objective of software transportability is achieved. This presents far less of a technology transfer problem than in the area of electron devices, for example, where issues of productability and yield are concerned.

On the other hand, an approach must be found for infusing laboratory developed systems and software technology into prime contractors without inhibiting their creativity or transferring risk to the government. To attempt to do otherwise would be in direct conflict with the directives of higher authority both within the Department of Defense and from the President's Office of Management and Budget.

Much of the technology transfer will likely be on a voluntary basis. This has been done successfully in the past both for hardware and software. Since the physical integration of electronics equipment with the airframe is a far more severe problem than with other platform types, many of the decisions on avionics are left to the airframer. Yet many of

our advanced developments do end up on aircraft because the airframers propose them. The existence of a laboratory test bed where new technologies can be demonstrated and validated goes a long way toward bridging the technology gap.

There are several major advantages to performing much of the avionics development in a laboratory environment. Perhaps the most important is that of off-line risk reduction. More and more of the risk in avionics systems will be at the systems level. If the traditional "bottom up" approach of avionics integration is followed, it will mean that the major problems will occur near the end of full scale development where there is little slack time left and the cost and schedule impacts are greatest.

Although much of the work will end up in a test bed at a government laboratory, most of the actual development will be performed by contractors, the same ones who will be involved in the full scale development and production of new aircraft.

In addition to providing a common forum for the development and validation of new technologies, these assets will be needed to assure that the standards which must be imposed are workable and effective. While there is no intent to inhibit industry initiative or the introduction of new technology, it is imperative that standards for interfaces, data format, and protocols be rigidly enforced to realize our objective of interoperability and reduced support requirements. The existence of an off-line test bed facility allows standards to be validated before they are imposed on a major aircraft procurement and later found to be unworkable.

Finally, an in-house facility is required to evaluate competing proposals effectively. Although the potential performance of a radar or communications link can be predicted analytically, the performance of a distributed tactical data handling system cannot. In order to effectively evaluate proposals for the kinds of digital integrated avionics systems under consideration, it will be necessary to have a base line from which to assess their performance and a simulation capability to verify the predicted performance levels.

4.2 STANDARDIZATION

Standardization has long been an objective of the Department of Defense. Its direct economic benefits are obvious. Uncontrolled proliferation of different equipment types results in wasteful duplication of effort for development and acquisition of the equipment and excessive logistics support costs. Now, however, with the President's NATO initiatives, standardization and interoperability have become key considerations of foreign policy as well.

One of the major reasons for our failure to achieve a greater degree of standardization within the Department of Defense has been the explosive rate of advance of technology. Standardization at the equipment level has been difficult to enforce because of the continuing introduction of new products with significantly improved performance. This led to the present approach toward standards that are "technology independent", such as interfaces, protocols, data formats, and instruction sets.

Theoretically, the development of technology independent standards should involve less political and economic considerations than equipment standards, because they are not as closely related to issued affecting production capabilities and competitive advantages.

Even these standards may be difficult to enforce, however, since the military market constitutes an insignificant percentage of the total microelectronics market and the profit margins in the commercial market are much larger. Therefore, the military impact on decisions regarding microcircuit manufacturing capability is minimal. In recognition to this fact, representatives of the DoD are participating in many non-military standardization activities such as the Purdue International Workshop on Industrial Computer Systems, as well as a multitude DoD and NATO standardization committees. Only if a large enough share of the microelectronics market can agree on standards is the situation likely to stabilize.

Earlier problems with standards were primarily concerned with enforcing them within government and resisting the ever present temptation to waive the standard to save money or obtain non-standard equipment with improved performance. Now, however, in digital technology the government collectively may not carry enough weight to impose standards or insure a supply of spares.

5. CONCLUSION

Future avionics system concepts will represent a significant departure from the traditional "black box" approach. Although significant advances have been made in the performance of avionics subsystems, the basic system organization has remained essentially constant. With the advent of digital avionics, we are no longer constrained by the traditional organization of "black box" subsystems.

The hardware to implement these new system concepts is available. The major challenges will be in the areas of systems, software and management. Unfortunately, experience has shown that problems in these areas tend to remain invisible until very late in the development cycle and often continue well into operational deployment.

Management of these new concepts within our own present organizational structure will

require crossing system and subsystem boundaries that have been rigidly defined in the past. This includes not only those functions usually thought of as avionics, but other on-board electronics functions such as aircraft flight control and electrical systems. Our internal organization has tended to parallel the organization of our systems and subsystems. Changing the system organization will necessitate cooperation between groups that have very little interaction in the past.

In addition to the technical and management problems associated with implementing a new system concept that performs as expected, of equal importance are the issues of standardization and interoperability. To address these issues requires cooperation between diverse groups within both the DoD and NATO. This can be a slow, time consuming process, yet it must be accomplished as an integral part of the development, or the resulting systems cannot be considered a complete success, regardless of their individual performance.

The Navy approach to the development of these systems can be characterized by three key features:

- We are starting early with systems development "off-line".
- We will be using a structures design approach which will stress simplicity.
- We intend to perform extensive simulation and validation to insure that our systems concepts are proven prior to their use in a major aircraft development.

We can no longer afford to be preoccupied with hardware at the expense of software. In past systems software was often treated as just another data item. Future systems plan to use programmable hardware to the extent that the "system" and its functions are largely undefined without the associated software. By approaching the systems issues early and following a conservative approach, we hope to avoid many of the problems of past systems.

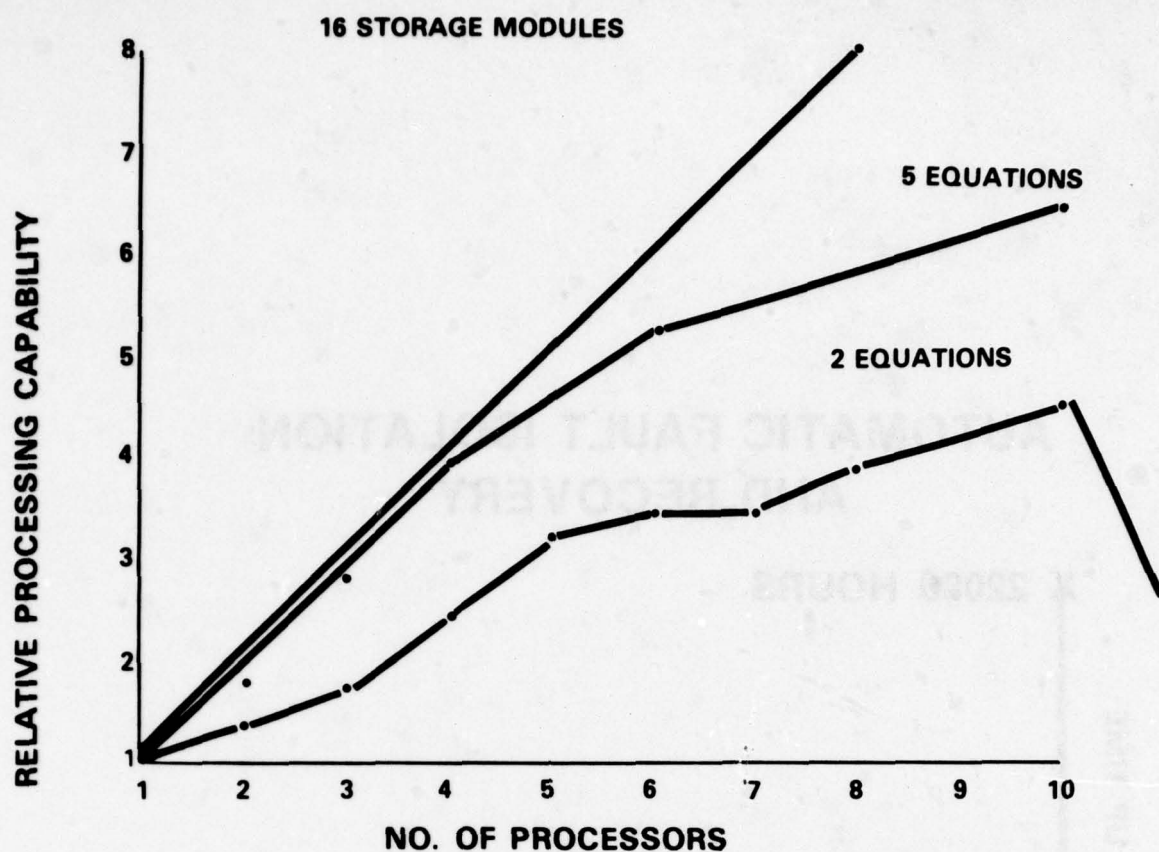


Fig.1 Relative processing capability vs. number of processors

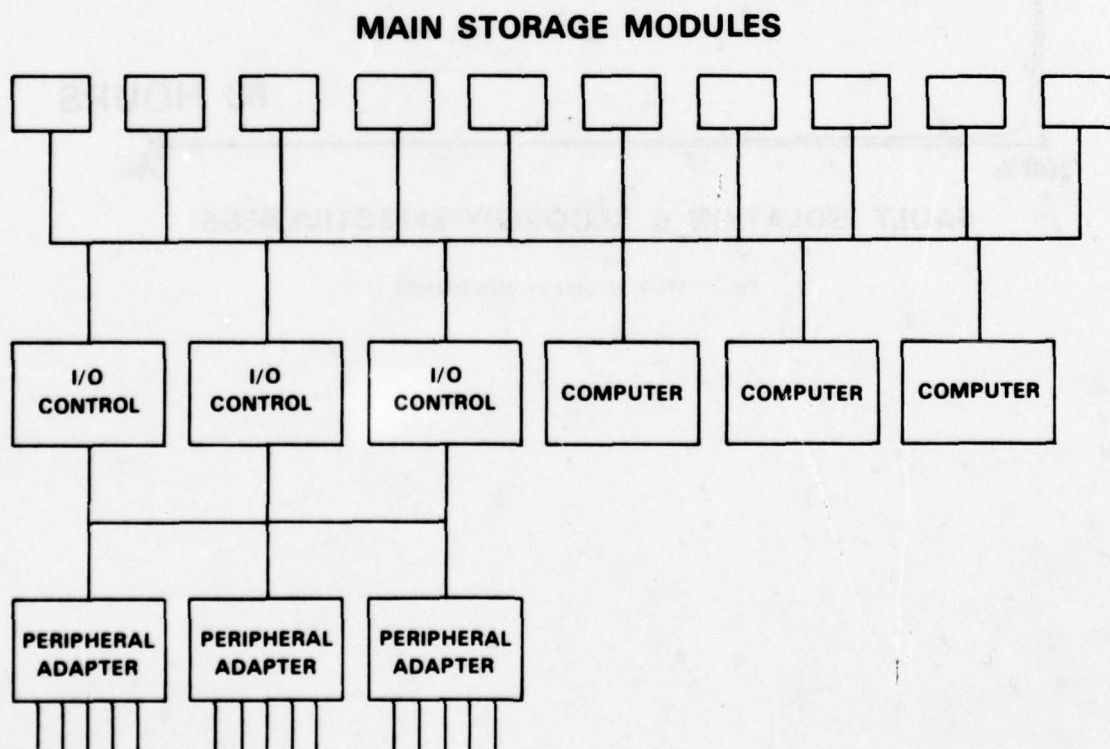


Fig.2 Real time command and control system

AUTOMATIC FAULT ISOLATION AND RECOVERY

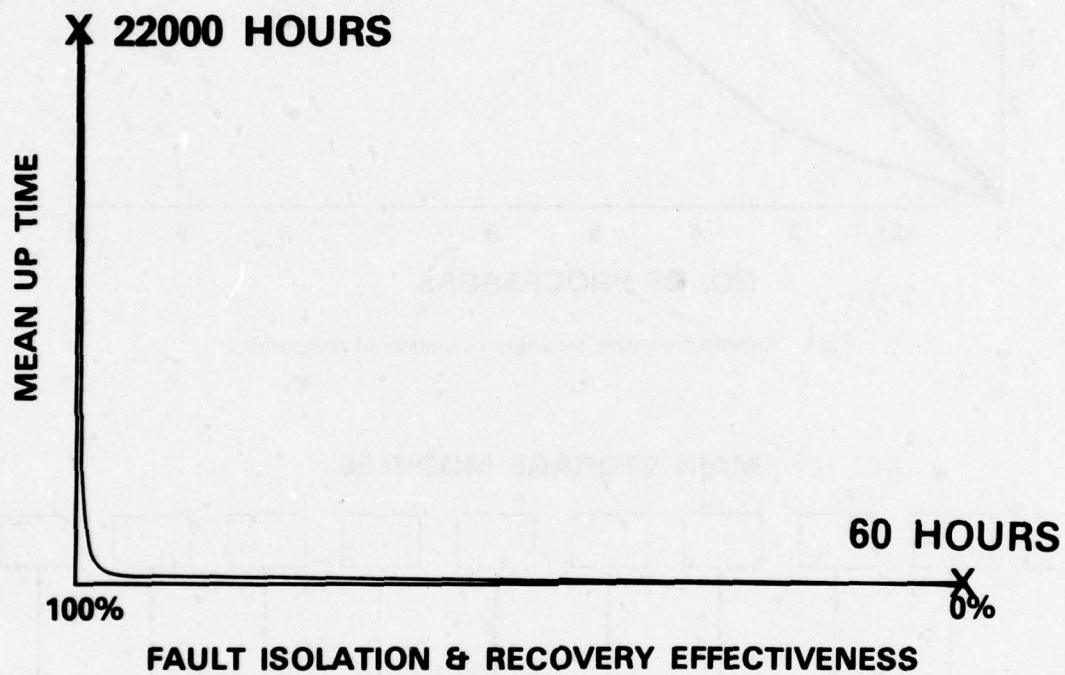


Fig.3 Mean up time vs. effectiveness

SOME TRENDS IN DATA ACQUISITION DISPLAY AND CONTROL

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SUMMARY

The advances in data processing in the last decade have been tremendous. While the comparable areas of data acquisition, displays and controls have not made the same order of progress significant advances have been made. This paper reviews this progress and examines possible trends. Active and passive sensor systems are reviewed as well as the display and control technologies available. In particular, uncooled FLIR and microwave radiometry trends are examined in the field of data acquisition and CRTs, LLD arrays, liquid crystals and plasma panels are considered in the display area. Examples are drawn from the fields of air-to-air combat and RPV control to illustrate the differences and similarities between tactical system requirements in different areas. These examples are also used to illustrate some of the outstanding problem areas. A final section describes the need for standard system description languages and interface specification to aid the total system design.

1. INTRODUCTION

The availability of suitable sensors and display systems forms the major limitation on the performance of tactical systems. The array of processors and processing techniques is now extremely formidable and in general there are available techniques to provide real time processing capability to meet our systems needs - albeit at a high cost for some of the more complex systems.

As with all systems however the tactical processing system is only as good as its input data. Similarly unless the processed information is displayed to the human operator in a form which he can readily assimilate, it is of little value.

In the last few years the range of sensors available to detect targets so that the tactical situation can be assessed has grown enormously and a wide variety of sensors are to a greater or lesser extent available. These sensors indeed cover the entire field of chemical, physical, acoustic and electromagnetic measurements and it is obviously beyond the scope of this paper to consider such a range.

In this paper therefore only the electromagnetic sensors - in particular some of the newer passive sensors - are considered.

Display technology is also in a state of flux and a variety of new techniques are becoming available. In this field however, the CRT is still pre-eminent and forms the standard against which all displays are measured.

Finally, there remains the problem of display content and two examples of the possible use of tactical displays are given.

2. SENSORS

2.1 General

As was mentioned in the introduction, the sensors considered operate in the electromagnetic region. For reference purposes, Figure 1 shows the frequencies and wave lengths of the various parts of this region.

Most of this spectrum can be surveyed by sensors of one sort or another ranging from television operating in the visual range through radar systems operating at microwave frequencies down to RF detectors used in the VHF and HF for electronic surveillance purposes.

The increasingly hostile ECM and ESM environment to be anticipated on a battlefield has led to greater emphasis being placed upon the use of passive techniques for surveillance and research and development in passive sensors is taking place using:-

- a) low light level television techniques
- b) infra red techniques
- c) microwave radiometry.

In addition, the advent of the mini RPV with its potential for collecting tactical information at low cost has led to the need for the development of small lightweight low cost sensors.

The three most promising developments in this area are:

- a) The charged coupled devices for visible (and near infra red) frequencies
- b) The pyroelectric vidicon for infra red frequencies
- c) The microwave radiometer for microwave frequencies.

CCD's have been discussed extensively in recent years and it is only a matter of time before semiconductor technology provides devices with the same (or even higher) resolution as a conventional camera tube. Interesting though such devices are, they can be thought of as solid state elements which may ultimately replace their thermionic equivalents. Figure 2 shows a typical CCD structure.

The remaining systems offer the potential of providing low cost sensors for both ground and airborne use and as such should be discussed further.

2.2 The Pyroelectric Vidicon

Pyroelectricity was one of the many effects investigated by 19th century physicists, in this case D. Brewster and reported by him in a paper published in the Edinburgh Journal of Science in 1824.

The effect occurs in certain crystals which on undergoing a change in temperature produce a surface charge in a particular direction as a result of the change in its polarisation with temperature. Reference 1 describes this phenomenon in detail.

All IR sensors must operate in the IR windows of the atmosphere (Figure 3) and since Planck's Law shows that black bodies at 300°K have their peak radiation at a wavelength in the region of 10 microns, it is essential that any imaging sensor operates in the 8 to 13 micron band.

Of the many pyroelectric materials known², triglycinesulphate (TGS) is the most widely used.

Since a pyroelectric device operates on temperature change, it is suitable for operation as an uncooled thermal sensor and was proposed as such by Hadni in 1965 and first produced by Le Curvenec³ in 1969.

For any uncooled sensor, the following requirements must be met.

1. It must operate above a reasonable temperature range;
2. It should have a reasonable frequency response;
3. It should potentially be of low cost.

Since cadmium mercury telluride (CMT) - which is the other obvious candidate for an uncooled thermal imager - has a poor low frequency response, TGS systems currently appear the most suitable for low frequency signals. Figure 4 shows the variation of specific detectivity D^* with frequency for these systems and it will be seen that this value varies between about 10^9 at low frequencies to about 10^8 at about 1 KHz. It should be noted that these values D^* are much lower than those obtained from cooled detectors which are of the order of 10^{10} to 10^{11} at 10 μm .

The pyroelectric device itself is a vidicon based tube with a target made of TGS. Several companies including English Electric Valve, Philips and Heinmann GMBH have produced such tubes.

As had already been discussed, the pyroelectric vidicon operates on changes in incident radiation and not the radiation level itself. Because of this some form of modulation is required to produce a stable thermal image. The modulation systems most commonly used are panning and chopping. The panning approach is to use an optical modulator and is shown in Figure 5. In this system, the scene is panned backwards and forwards across the target by means of the modulator so that the temperature is changed. The resultant image is then stabilised electronically. This system gives good results, but there are several problems with this approach:

- a) cooling wake
- b) pan reversal transients
- c) loss of resolution in the panning direction.

The cooling wake problem is due to the cooling of the target after a heated region vanishes from the field of view. Since this is a negative temperature change, the target responds and a negative image is produced which has the effect of masking any small objects in the field of view.

Pan reversal transients are due to the thermal lag in the material. As the panning motion is reversed, the image persists (possibly for several cycles) and so causes confusion. This effect can be minimised if continuous panning is performed and a rotating prism is most commonly used to perform this. Typically, the prism rotates at 180°/sec thus rotating the image on the screen at this frequency. The image is then stabilised electronically. The image still however exhibits thermal streaks.

The chopping approach is simply to apply optical modulation by means of a shutter. When the shutter is closed, a negative image is produced. This image may be inverted before display to produce a second positive image from the display.

Currently, the performance of pyroelectric vidicon is such that minimum resolvable temperature differences of less than 0.5°C can be detected and 200 line TV performance has been demonstrated. Figure 6 shows the performance of a conventional TGS system and that of an alternative pyroelectric material deuterated tryglycine fluoberyllate.

While it is most unlikely that the performance of these sensors will ever approach that of the cooled thermal imager, the PE vidicon is certainly approaching the state when it provides a low cost alternative to conventional IR systems. As such, it may find substantial use particularly in mini RPV's.

2.3 Microwave Radiometry

The microwave radiometer operates in the various atmospheric windows in the microwave frequency. Figure 7 shows these windows and radiometers are typically designed to operate in the 35 GHz region although some work is proceeding at 90 GHz as well as at the lower frequencies.

Such a radiometer receives both reflected and emitted radiation from the scene and Reference 4 shows some results obtained by the Naval Weapons Centre China Lake.

Figure 8 shows in schematic form the component elements of a radiometer. The antenna is typically the same type as a radar operating at the same frequency and the essential requirement is to achieve as low a noise figure as possible.

In assessing the performance of a radiometer, the most important parameters are:

- a) The target to background radiometric temperature difference. This depends upon the reflectivity and emissivity of the target and the apparent sky temperature.
- b) Attenuation of the radiation from the target by the intervening atmosphere.
- c) The emission of the intervening atmosphere.
- d) The proportion of the radiometer beam width occupied by the target.

Based upon these criteria, Dicken and Wright⁵ have derived the curve shown in Figure 9 for a typical radiometer. This shows that even in rain, a radiometer operating at 30 GHz can detect a 10 square metre target at about 3 KM. Thus, in all but the most severe meteorological conditions a radiometer should be capable of detecting a stationary main battle tank at about 4 to 5 KM. This capability is of obvious importance and because of the passive nature of this type of sensor coupled with its all weather capability, it is anticipated that such sensors will play an ever increasing role in future tactical systems.

3. DISPLAYS

3.1 General

There are now available a wide variety of displays for use in tactical systems. In order to choose the most appropriate display, the following parameters are important:

1. Frame rate
2. Contrast ratio
3. Ambient illumination
4. Symbol characteristics
5. Resolution
6. Bandwidth

These characteristics are interdependent and for example a low frame rate causes flicker unless either scan conversion or a long persistence display medium is used. If the latter approach is taken then in general the display has low brightness and a poor contrast ratio. To avoid the flicker problem frame rates about 30-35 Hz are normally considered necessary although as shown in Figure 10 this frequency varies with brightness. This is true for a single display, but because the increased sensitivity of the peripheral vision of the eye flicker can be observed up to about 50-60 Hz if the display is present only in the periphery of the operator's field of view. This is of obvious importance when an operator is monitoring not one but several displays.

Figure 11 shows the frame rates of some of the more commonly used sensors and it will be seen that to provide a bright display with no flicker scan conversion is required.

Despite the advent of alternative displays such as light emitting diodes, liquid crystals,

plasma panels, etc., the CRT because of its versatility and mature state of development is still the dominant display in tactical systems. To illustrate the range of uses for CRT displays, Table 1 indicates the most commonly used phosphors and some of the applications to which they have been put.

3.2 Colour CRTs

It is somewhat surprising that despite the millions of colour TV systems in use colour CRT displays are still in their infancy for tactical systems.

The reasons for this are:-

- a) Colour CRT displays are low brightness;
- b) The shadow mask system generally used in commercial displays is a delicate construction and would not meet the environmental requirements of most military systems;
- c) The tube has limited resolution;
- d) There is still some arguments as to whether the increased effectiveness of colour in tactical displays is cost effective.

Of the colour tubes available, the penetron (Figure 12) is the most likely contender for military applications. This tube has a limited range of colours - typically four or five - but enables some colour coding of tactical information to be performed. The cost of such a system is of course higher than that of a monochromatic display since to achieve colour, the high voltage supply must be modulated.

3.3 Solid State Displays

There are a number of possible solid state displays for use in tactical systems. Table 2 shows some of these. The main problems for the use of these displays are:-

- a) With the exception of LEDs and LCDs the brightness of such systems is low;
- b) The cost of the matrix drive circuits currently makes the total display cost higher than that of a CRT;
- c) The resolution of such systems is much lower than a CRT.

The best resolution obtainable at the moment is from a plasma panel; Figure 13 shows the structure of such a panel. It has the advantages of providing reasonable resolution (500 x 500 elements) with a high contrast ratio which helps offset its low brightness.

The liquid crystal display offers a variety of advantages and has of course no brightness problems. Considerable work on these displays has been done - particularly by Hughes and the early problems of slow response and limited temperature range are gradually being overcome. This type of display has been described in detail by Slocum⁶.

Another display medium which shows promise is the light emitting diode array. Many materials exhibit light emitting characteristics and Figure 14 shows the most common in relation to the spectral response of the eye. A great deal of work has been carried out on high brightness LED displays and the Marconi Company have achieved 12000 ft lambert 100 x 100 matrix displays. This work is being carried out in particular for head up and helmet sight applications. The major problems of such displays are the high currents needed to achieve high brightness and the cost of the matrix drive elements.

3.4 Combined Displays

One common requirement of a tactical display is to present map information. This can be done by a computer generated map and Figure 15 shows such a map. The amount of map detail which can be stored on a computer is however limited unless an extremely large memory is provided. Such systems are not cost effective in comparison with the type of projected map display developed for aircraft use. The early versions of these displays suffered from the problem that while the fixed information (the map) was effectively displayed, the dynamic information could not be superimposed on this.

There are two current approaches to this. The first of these uses a rear port tube. In this approach, which is shown in Figure 16, the map is projected through a port at the rear of a CRT onto the face plate of the tube. The CRT is then used to write the dynamic information onto the display.

An alternative approach has been developed by Ferranti. In this system, optical mixing is used to superimpose the static information on that of a standard CRT. This technique is used in the Tornado and F18 aircraft to increase the flexibility of the projected map displays used in those aircraft.

3.5 Trends in Future Displays

Unlike the sensor area, the display field is still dominated by one technology - the CRT. While other display media have potential, they still require considerable development before they are as cost effective as existing CRTs. CRT technology is not static and the combined display approach allowing the combination of static information from a 35 mm film with dynamic alpha numerics and symbology will increase still further the flexibility of a CRT. At the same time, the type of combined display described above could be used with other display media when only limited resolution is required.

4. EXAMPLES OF TACTICAL DISPLAYS

4.1 General

Thus far, this paper has concentrated upon technology rather than applications. However, any system designer should start with the required application and from this decide the type of technology needed to solve the problem.

In the field of displays, as well as the technology to be used, great attention must be paid to the needs of the operator. The field of human factors is vast and in general is beyond the scope of this paper.

In general however great care must be taken to present the operator with the information needed to carry out his task. This in a form which is readily assimilated by the operator.

The type of information needed depends upon the operational environment and the time which is available to the operator to assess the information. The following paragraphs give some examples of this. These examples do not relate to any particular system, but are designed to present the types of system possible.

4.2 Mission Planning in a ground environment

To examine the information requirements to plan a mission, the following example is considered.

A remotely piloted vehicle is to be dispatched on an information gathering mission. It is required to prepare a flight plan which will cover the required area and to specify the tasks to be performed. It may be necessary to modify this flight plan during the mission to update the tasks to be performed and to carry out a new task which has a higher priority.

The first set of information needed by the mission commander is the current status of the vehicle. Figure 17 shows a possible CRT display which occupies only a portion of the available display area and is always available to the commander.

This data shows the current location of the air vehicle, the remaining flight time, the time at which the return flight should start, the time the next task should start and the duration of the task as well as a list of the remaining tasks.

To enable the mission to be planned, it is necessary to consider a variety of information. The approach taken is to operate the system at a number of different levels. A menu approach is taken so that the mission commander has maximum flexibility.

Figure 18 shows the top level of this menu. While Figure 19 shows the next level. Thus, the mission commander can input or update intelligence information, can display this data, can update both the particular task or mission etc.

By keying the intelligence input, the display format changes to that shown in Figure 20. This enables the commander to input intelligence data of the type shown.

Finally, the commander can select a symbolic mode (Figure 21) which indicates the location of the forces as specified by the intelligence input.

With this data, it is possible to proceed to the mission planning stage. A similar approach is taken to specify the tasks required and the flight plan.

The final symbolic display is shown in Figure 22. Although this appears confusing in monochrome, in practice a colour display is used and the tasks (figures) and any points (letters) are colour coded.

While it is not the intention of this paper to examine the rationale behind the display formats given, the following points should be considered.

1. The menu approach taken is a powerful technique. (It is of course standard for computer graphics applications.) However it is possible only because of the time available to the commander to input the data and to manipulate the system.

- 2) This interactive approach is possible because the commander is able to devote all of his attention to the task and hence he is able to consider the data at the various levels available to him.
- 3) Despite the above, the approach of providing different levels of data so that the operator is given the maximum flexibility is valid.
- 4) Great care should be taken to ensure that there is maximum legibility. Thus, during the mission itself, it is possible to superimpose a topographic map. While this is attractive, it tends to clutter the display during the planning phase and the symbolic presentation used is much easier to understand.

4.3 Airborne Tactical Displays

The second example considered is at the other extreme from the first example. In the previous example, the operator was able to devote his whole attention to his tactical task and was in a reasonably comfortable ground environment.

Consider now the situation of the single seat fighter pilot. The pilot has not only to fly his aircraft but also to search for and identify targets and then to decide upon his attack tactics. All of this being done in an aircraft which is flying at high speed so that both the pilot's environment and the time available for him to decide upon a tactical plan is limited.

This problem is not too difficult for a pilot if he is faced with only one potential target, although even there he is faced with the problems of:-

- a) Identification
- b) Determination of the best interception manoeuvre
- c) Energy management
- d) Fire control
- e) Disengagement.

While at the same time monitoring his fuel and ammunition state and flying the aircraft.

The pilot of a modern fighter therefore requires considerable assistance to perform this task and unlike the previous example, he has not the time available to operate interactively with the aircraft computing system. Instead, the available tactics should be stored in the system and the best available shown to him on a situation display as well as on a director display. The pilot is of course allowed to override the system if there are additional factors which are not known to the system.

The problem becomes much more difficult if there is more than one target.

Consider the situation shown in Figure 23. In this case, the pilot is presented with not one but five potential targets. It is assumed that the aircraft radar has processed the raw data so that target speed, height and direction are available.

The pilot is now faced with the problem of planning his tactics against these potential targets. He now has to select the best target to attack and to decide which attack profile he should adopt. To do this, he in fact needs more information.

One possible approach therefore is to use the aircraft computing system to calculate the target positions at intercept and to classify the targets in terms of time to intercept.

This results in the situation shown in Figure 24. This display shows the target positions at the time the first intercept would be made, assuming that the targets maintain their current tracks and speed. The situation display is obviously updated continuously.

The pilot is then able to see that if he uses a rear hemisphere attack on target 1 he will pass in front of target 2 and so present that aircraft with a firing opportunity. This in turn means that either he should carry out a front hemisphere attack on target 1 and then engage target 2 or engage target 2 in a rear hemisphere attack.

The pilot having selected the target, the system provides him with steering information to engage that target while the situation display continues to show the projected positions of the remaining targets during the attack. The pilot is thus able to monitor the situation and to consider any threats. In particular, the display should indicate any targets which are moving into his rear hemisphere where the system will no longer be able to track them.

A further problem arises however when the targets are of different types and indeed when some are potentially friendly. In these circumstances, the pilot may find that he is drawn out of position by a friendly aircraft and thus hostile aircraft are allowed to penetrate. Alternatively, he may find himself committed to attack an enemy escort fighter and thus allow enemy attack aircraft to continue their mission.

To avoid this situation, assuming that a long range visual identification system is carried, the system should compute a track which allows the pilot to fly such that he is able to identify visually each target in turn without precluding attacking the other (as yet unidentified) targets.

Figure 25 shows the situation when targets 1, 2 and 3 are identified, the dotted circles showing the limits of the postulated visual identification system. This display is of course cluttered and in practice a display such as that shown in Figure 26 is preferable. This shows his projected track and the points at which various targets come within visual identification range along that track. Once again the system provides director information to enable the pilot to fly such a track and continuously updates the situation display shown.

Once again, it is not intended to suggest that this is the best possible approach to the problem, but to illustrate some of the problems of tactical displays.

In this particular case, there is limited decision time available and the operator is not able to interact with the computing part of his system in the same way as the operator in the first system. Indeed, the pilot need not be aware that he is operating a computer any more than he needs to know that he is interacting with the world's largest switching network when he makes a telephone call.

5. FUTURE TACTICAL SYSTEMS

Having discussed albeit briefly the sensor and display requirements of tactical systems, it is of interest to consider the future requirements of such systems. As was stated in the introduction, the processing power now available is tremendous and can provide very sophisticated tactical data.

The technology of sensors and displays while not so all embracing as that of the processor is still very sophisticated.

There is however a tendency, particularly among the computer designers to consider the remaining elements in the system as peripherals. This is a dangerous avenue of thought since the system is a total entity and should be considered as such. Indeed, there are more difficulties and problems to be solved in the area of, for example, sensors than in the processor.

One of the major problems to be solved therefore is how to rationalise the system design of large-scale tactical systems. While this has been addressed in terms of the processor and in particular the software of the processor, it is by no means solved even in that limited area.

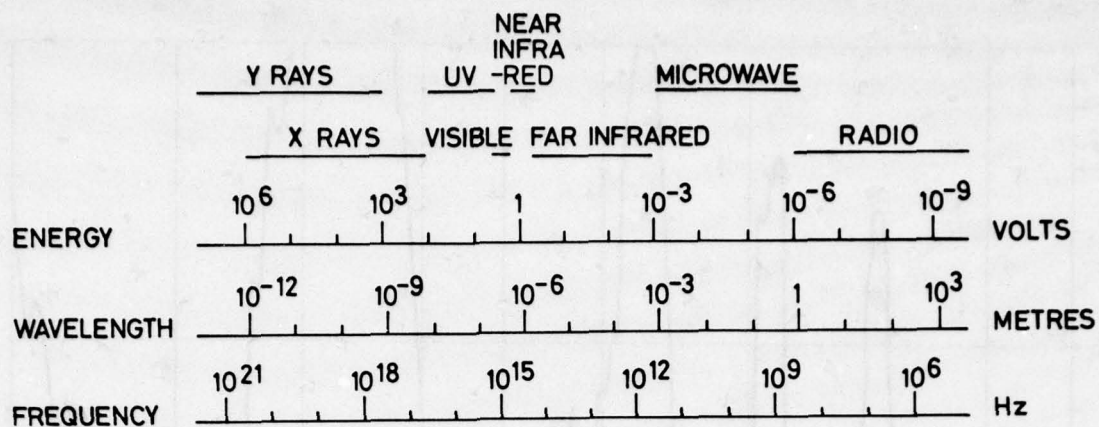
The overall system design is still very much empirical and there is a need to further develop system design and specification tools.

One of the more promising techniques is the 'prototyping' approach where a very powerful and flexible computer model is constructed of the system. This enables various alternatives to be considered before the system design is frozen.

For this approach to be effective however additional design tools must be developed. In particular, a 'system description language' should be produced which enables the essential hardware and software attributes of a system element (including its interface) to be simply and unambiguously defined. Such a language should allow the system model to be constructed and modified quickly and when a satisfactory system is established should enable clear and unambiguous specifications to be produced. Some work has been done in this field - notably by TRW in the US and by AUWE and Plessey in the UK, but a great deal more needs to be done. Without such tools, the capability of future tactical systems will be dictated not by technology limitations but by the problems of system design and management. It is not suggested that the above approach will solve these problems, but it should enable a more rational and integrated approach to the design of future tactical systems.

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BASIC RELATIONSHIPS: $E = h\nu$ $\nu = \lambda/c$ $c = 2.998 \cdot 10^8 \text{ ms}^{-1}$
 $E = hc/\lambda = 1.24 \cdot 10^{-6}/\lambda \text{ eV}$

Figure 1 Wave lengths and frequencies of EM spectrum.

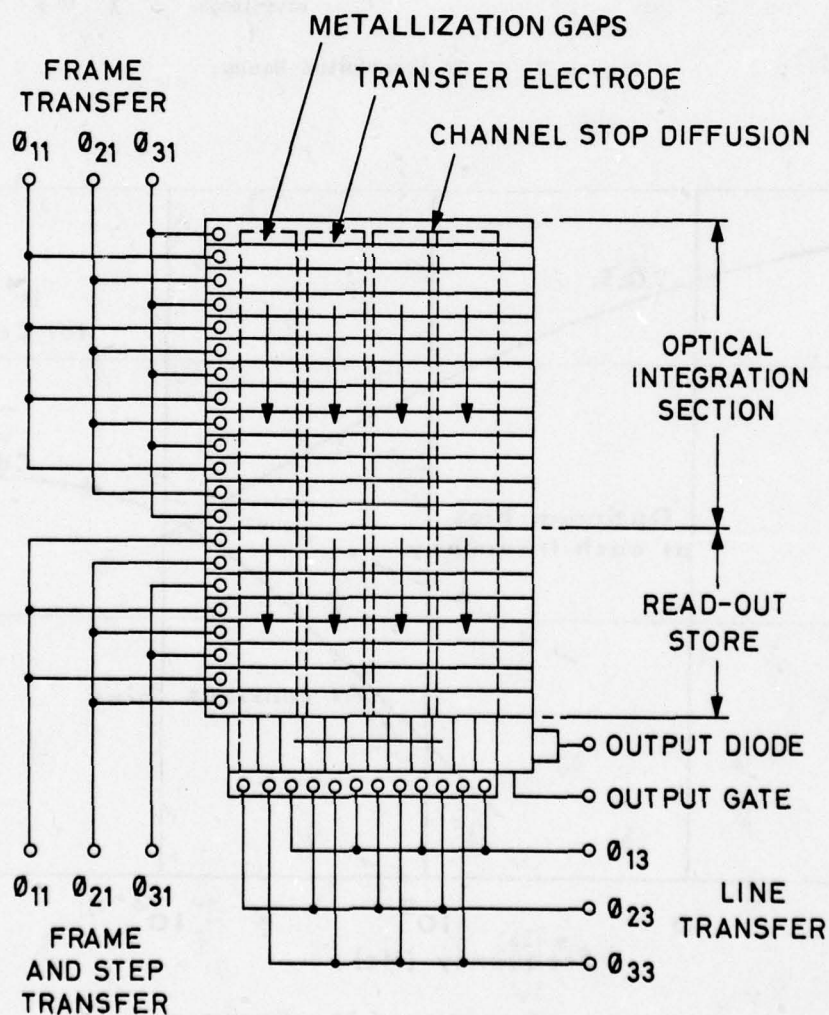


Figure 2 CCD Structure

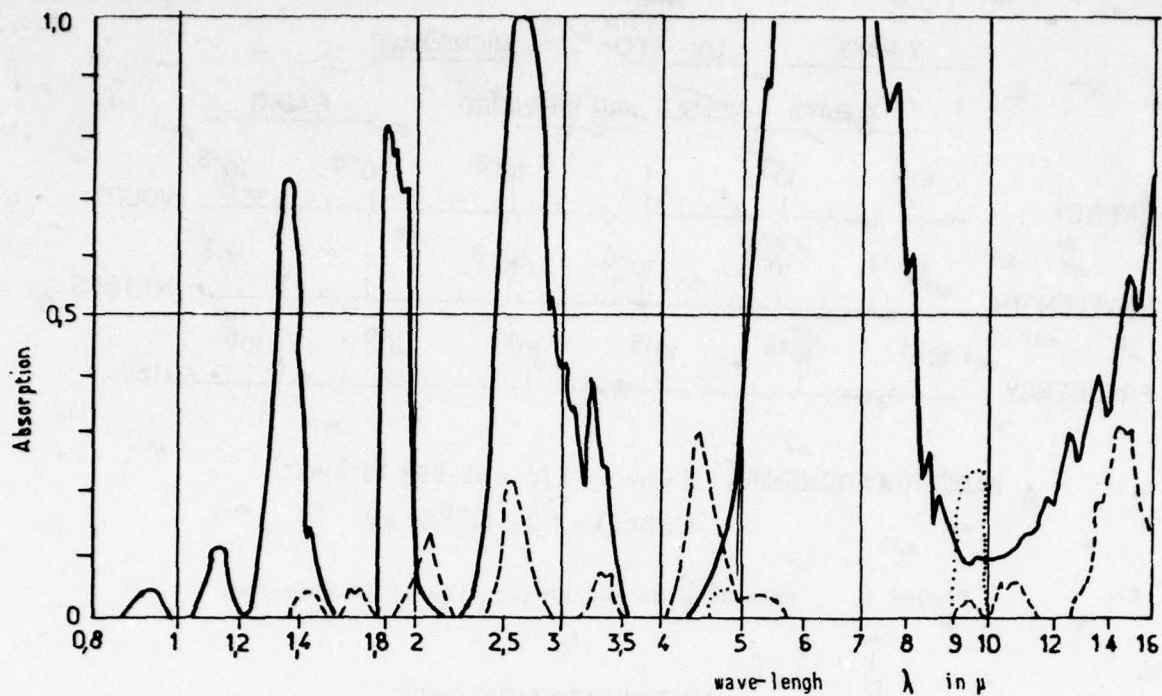


Figure 3 IR Absorption Bands.

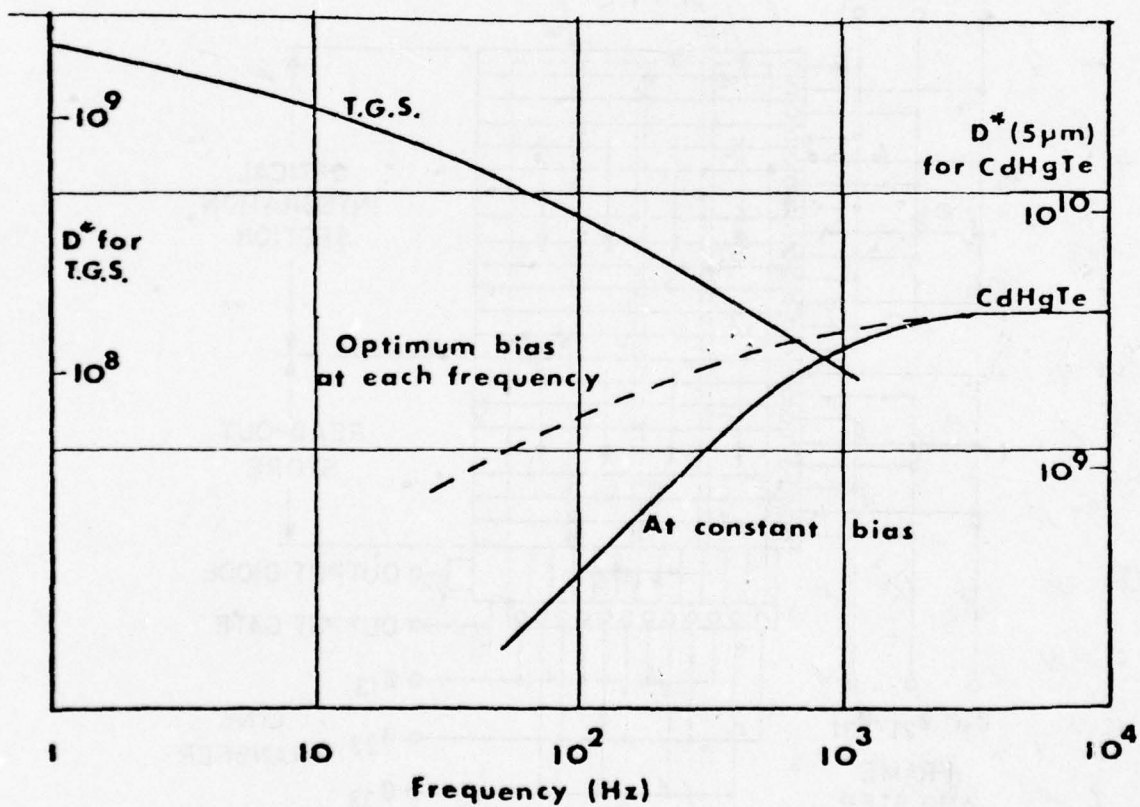


Figure 4 Comparison of D^* v Frequency.

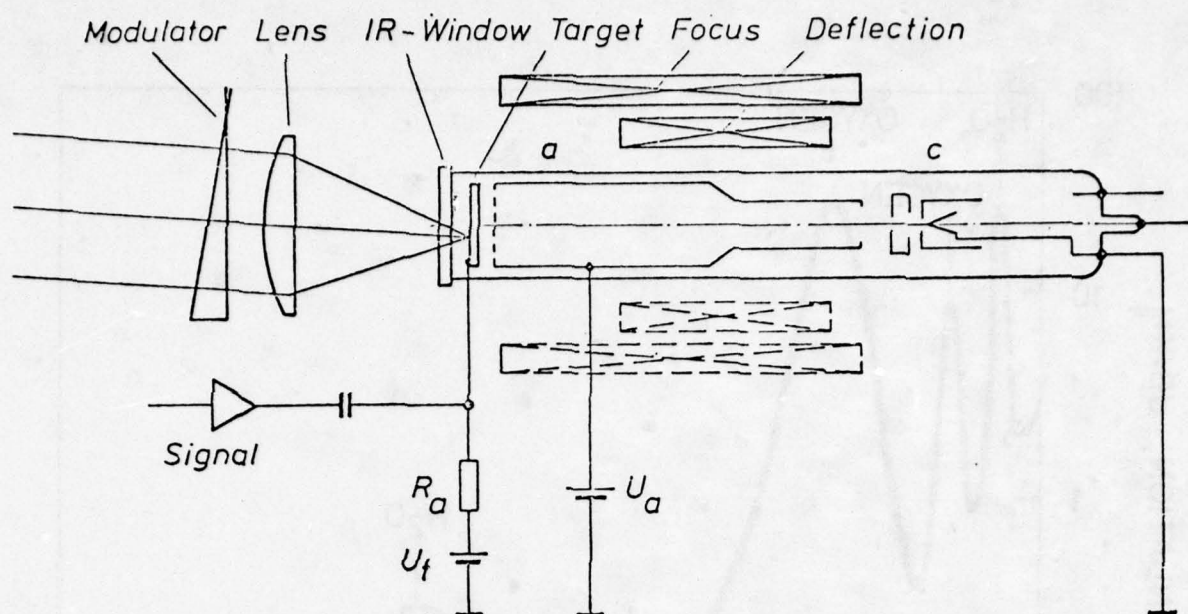


Figure 5 Pyroelectric vidicon schematic.

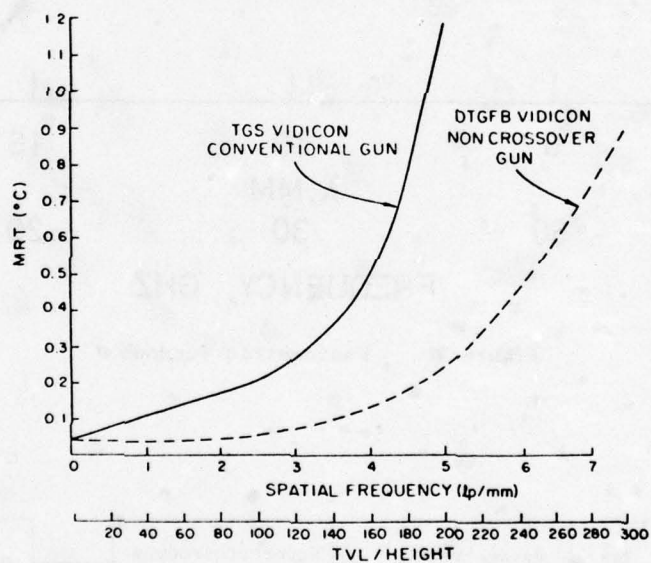


Figure 6 Minimum resolvable temperatures for pyroelectric materials

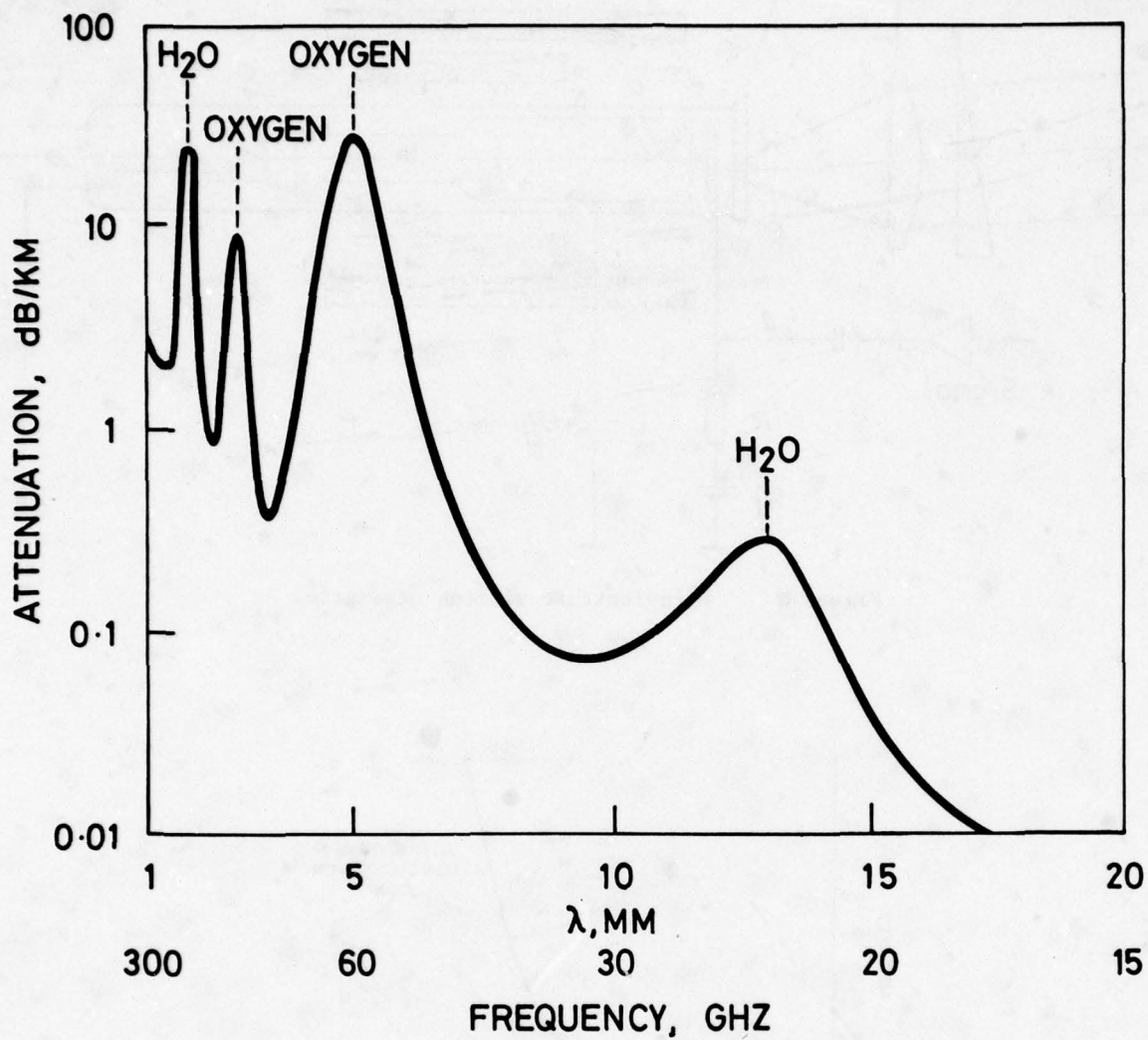


Figure 7 Radiometric windows.

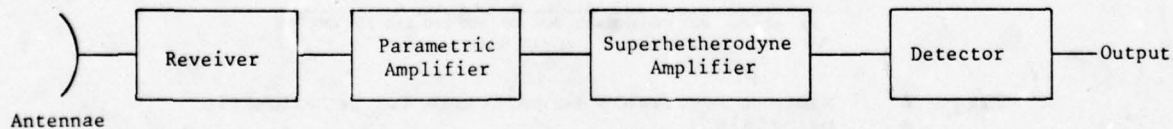


Figure 8 Typical Radiometer block diagram.

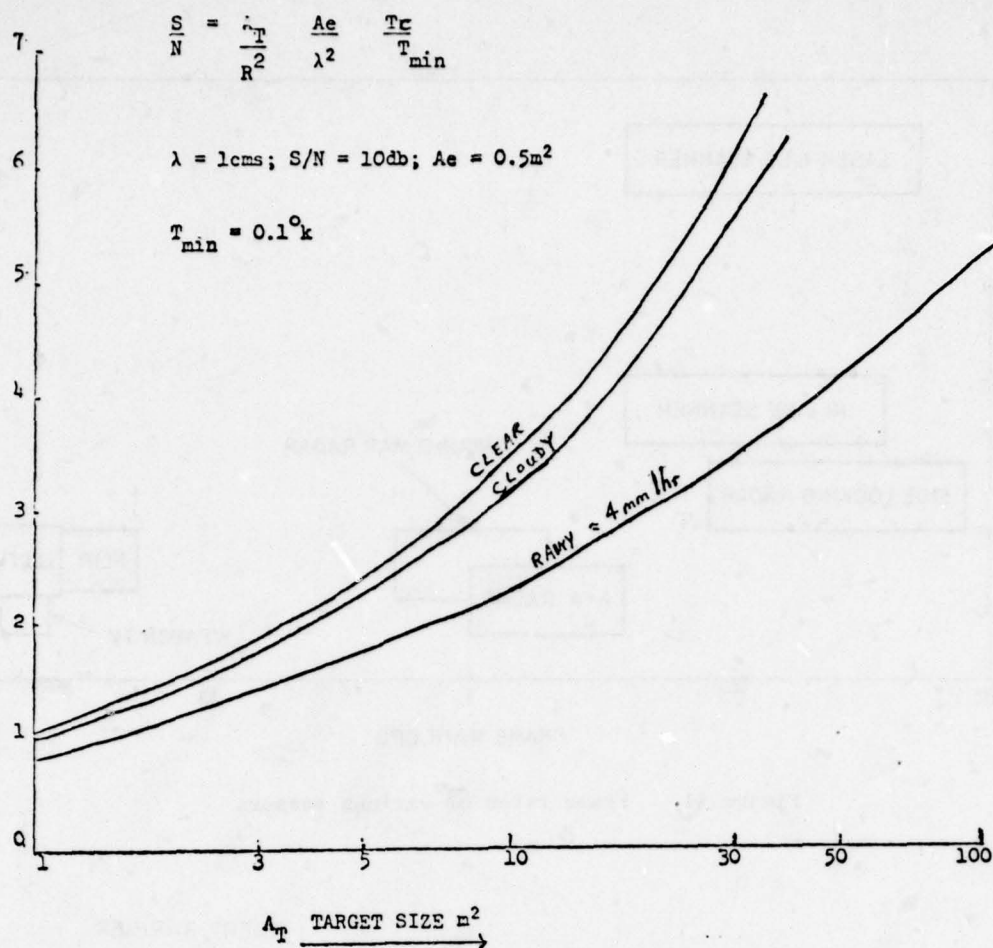


Figure 9 Radiometer performance.

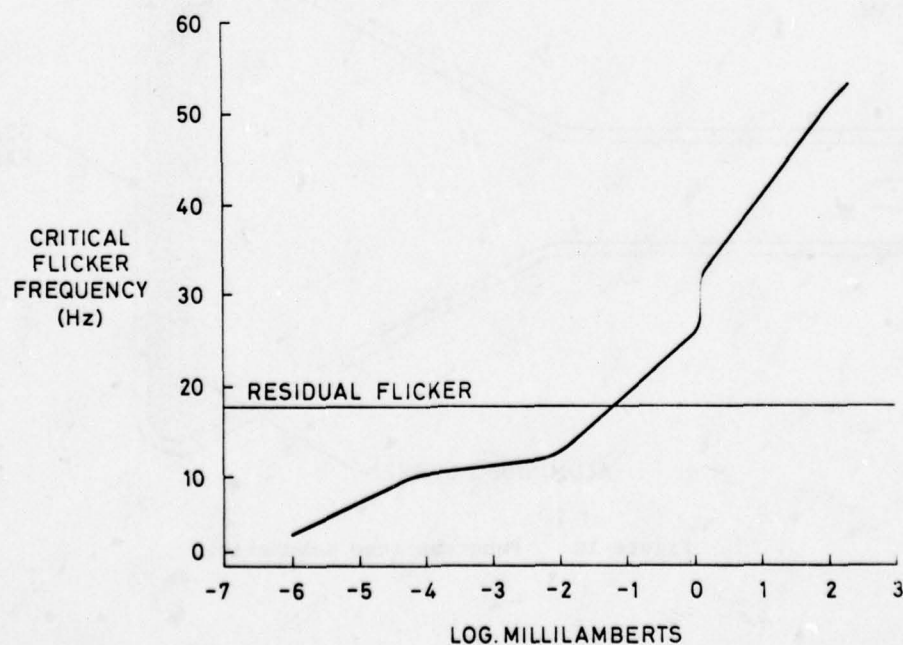


Figure 10 Flicker frequency v brightness

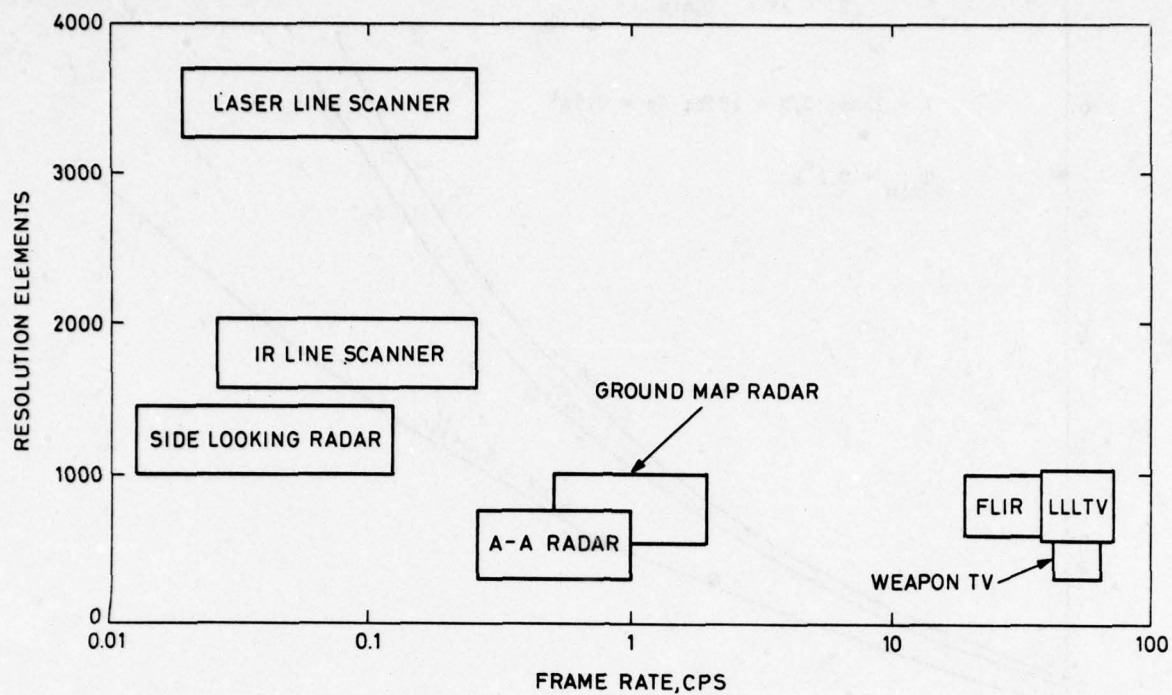


Figure 11 Frame rates of various sensors

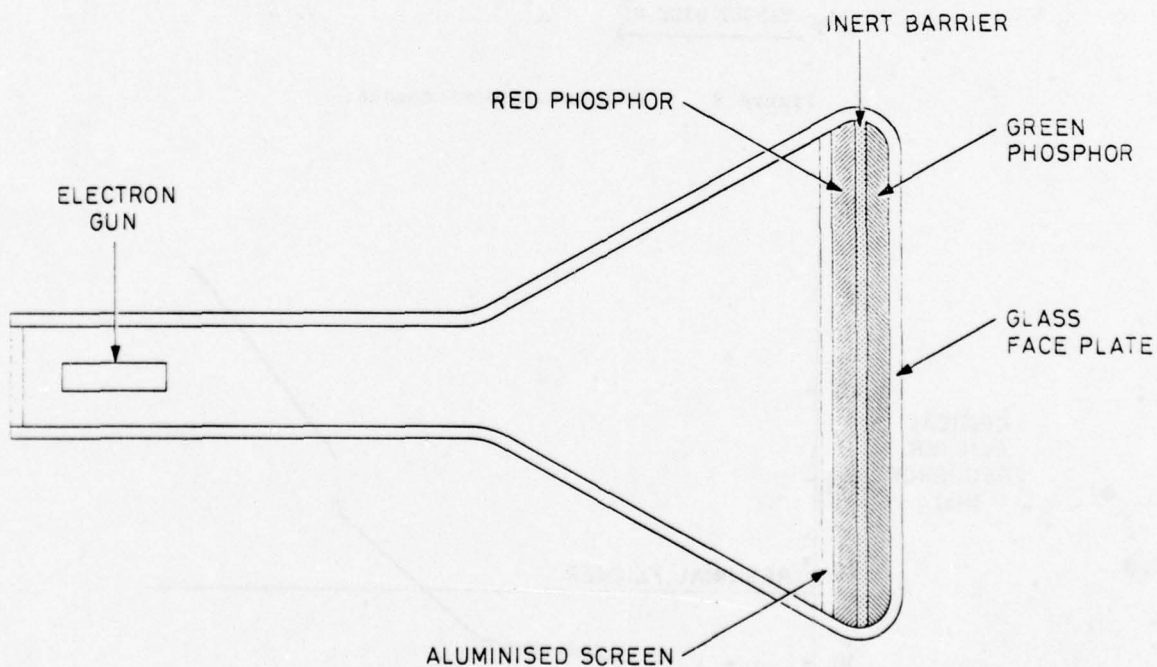


Figure 12 Penetron tube schematic.

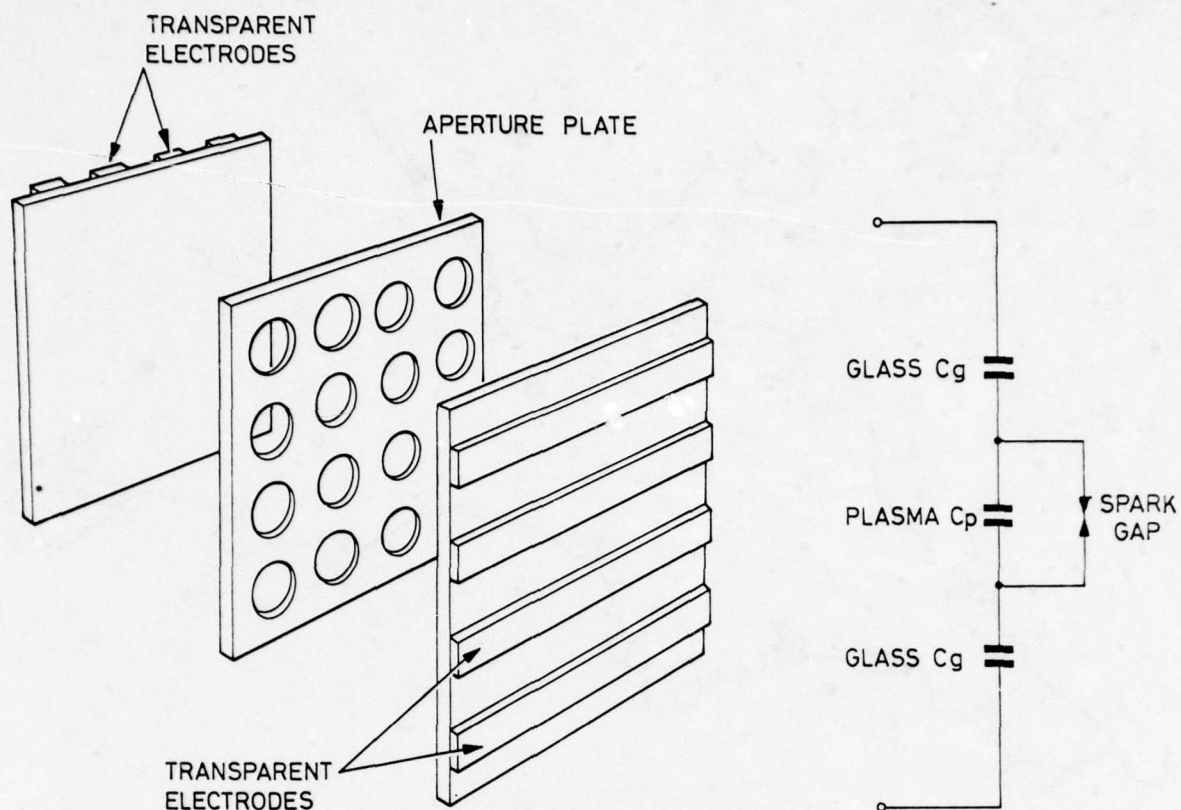


Figure 13 Plasma panel construction

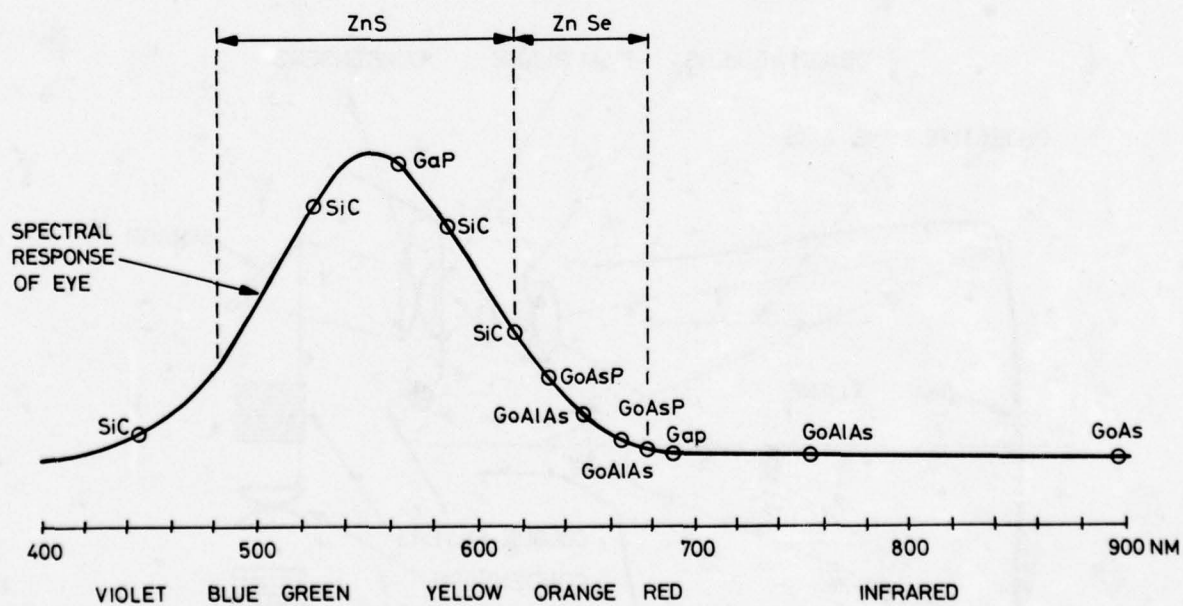


Figure 14 Light emitting diode spectral response

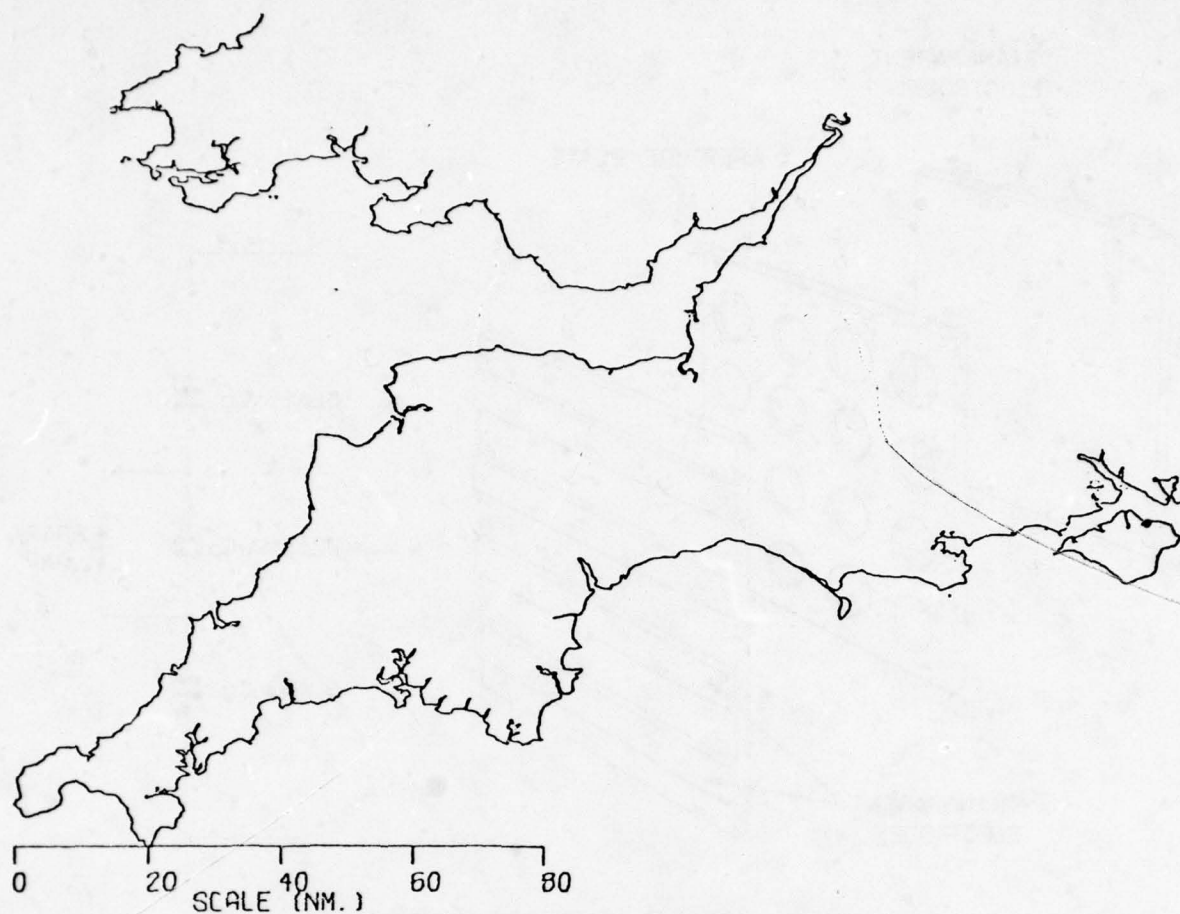


Figure 15 Computer generated map

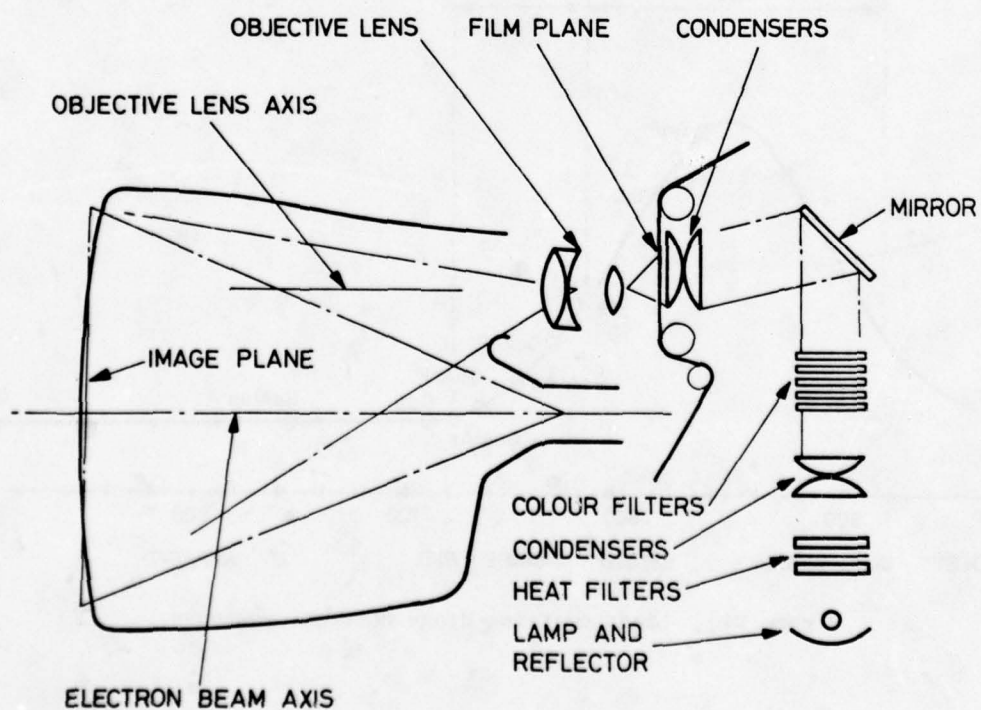


Figure 16 Rear port tube schematic

```

MISSION -- AV LOC ----- --:--
TIME LEFT  :-- NEXT TASK BEGINS --:--
RETURN TIME :-- NEXT TASK DURATION --
TASKS REMAINING -----
-----
-----
IN TRANSIT

```

Figure 17 Commander's status information

```

KEY

A INTELLIGENCE UPDATE
B INTELLIGENCE DISPLAY
C TASK UPDATE
D PLAN/REVISE MISSION
E METEOROLOGY

SELECT

```

Figure 18 Top level display menu

```
INTELLIGENCE UPDATE
```

KEY

1	INT CODE	-----
2	INPUT	
3	UPDATE	
4	DELETE	

SELECT

Figure 19 Intelligence update display

```

INTELLIGENCE INPUT

KEY

A INT CODE      - - - - -
B TIME          - - - -
C LOCATION      - - - - -
D FORMATION     - -
E SIZE          -
F MOVEMENT      - -
G DIRECTION     - - - -

SELECT

```

Figure 20 Intelligence input display

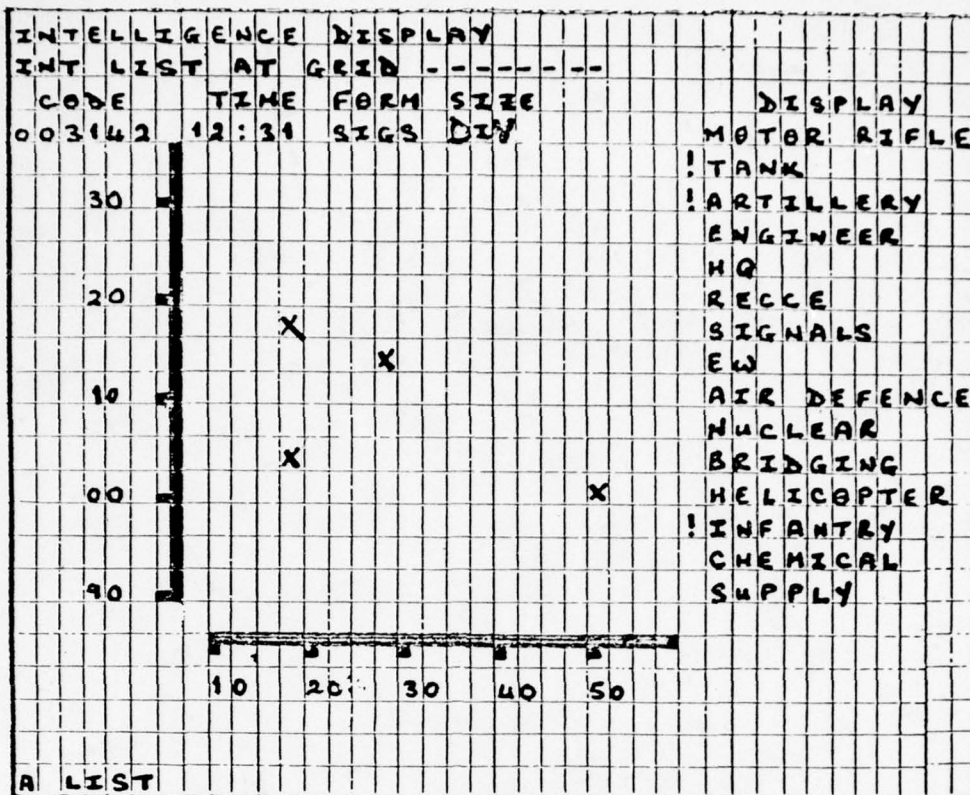


Figure 21 Symbolic intelligence display

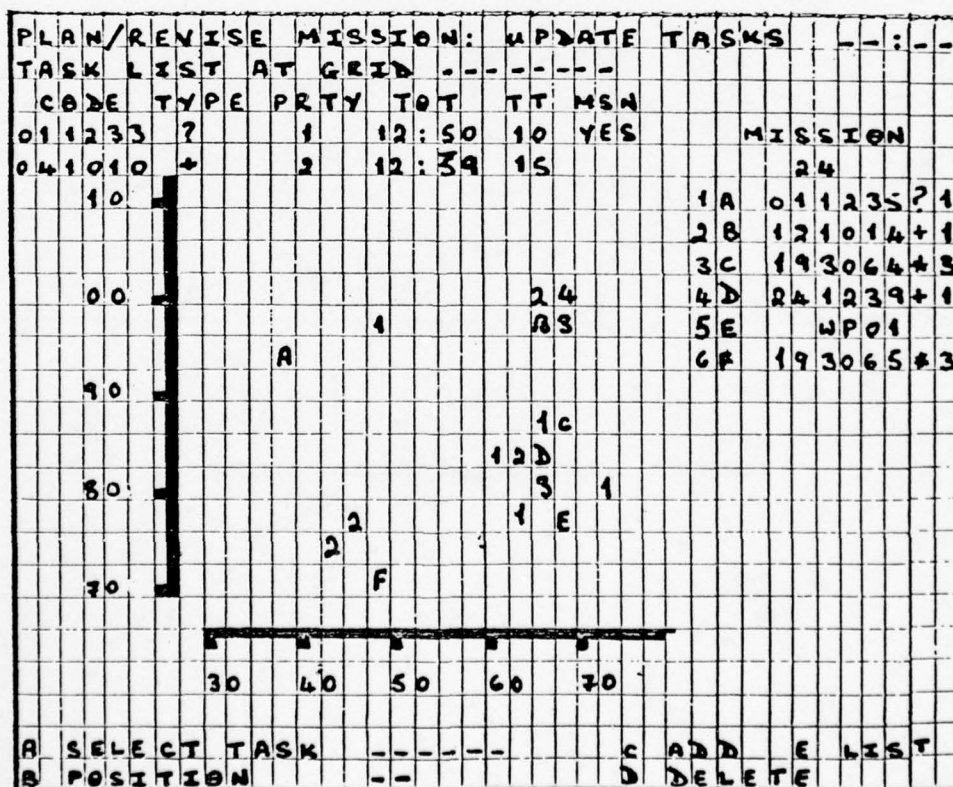


Figure 22 Composite symbolic display

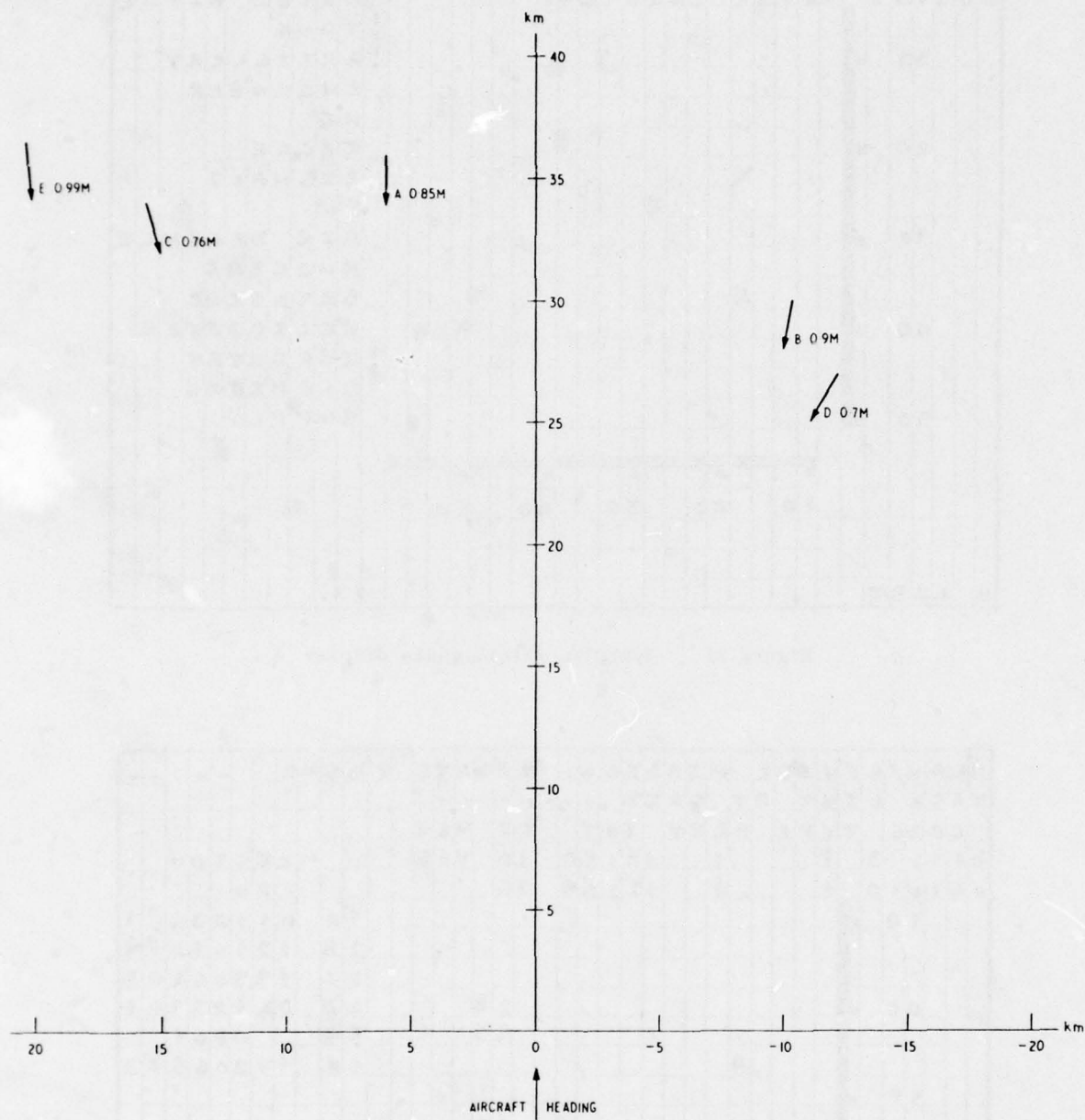


Figure 23 Basic target situation display

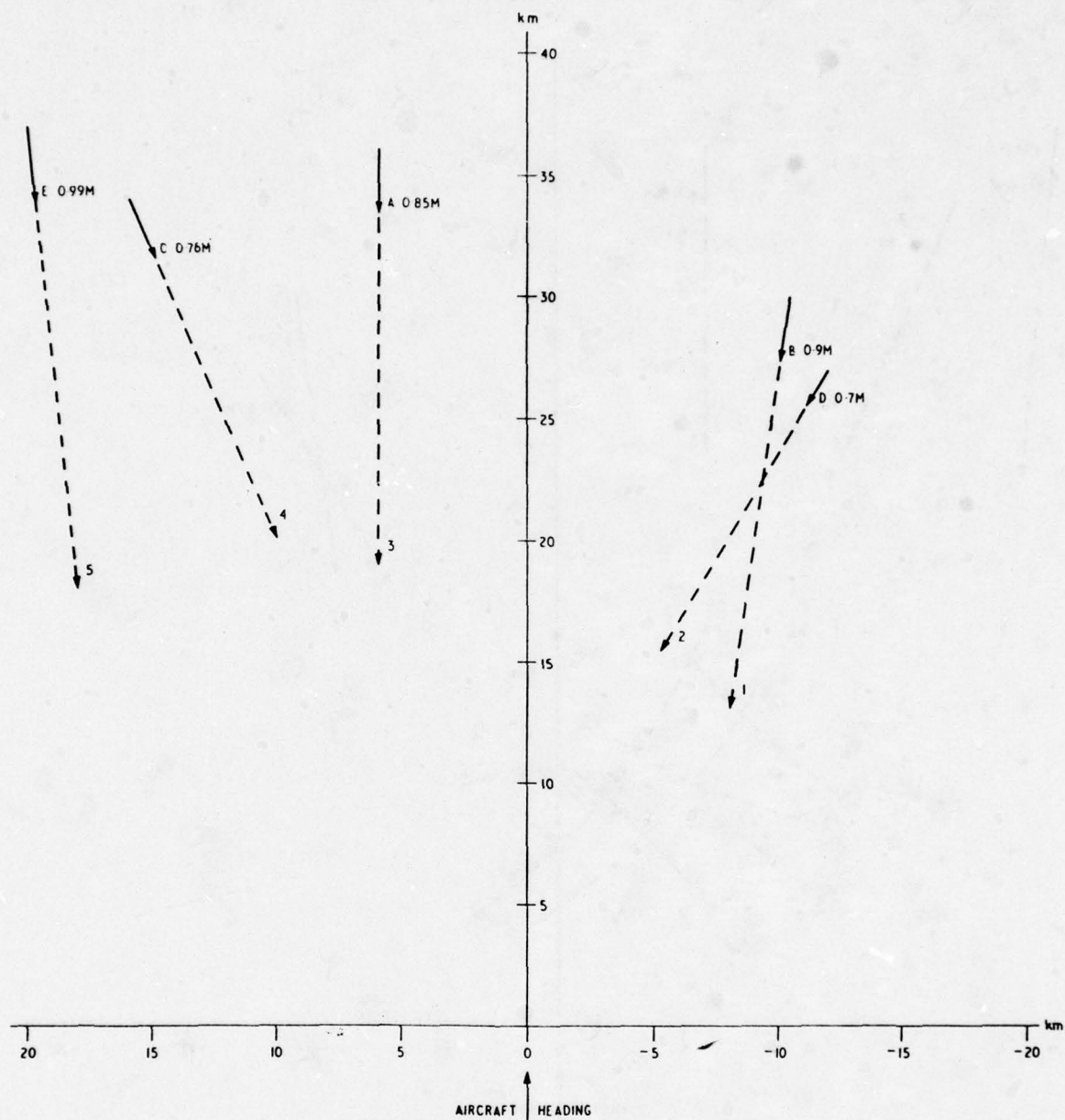


Figure 24 Projected situation at first intercept

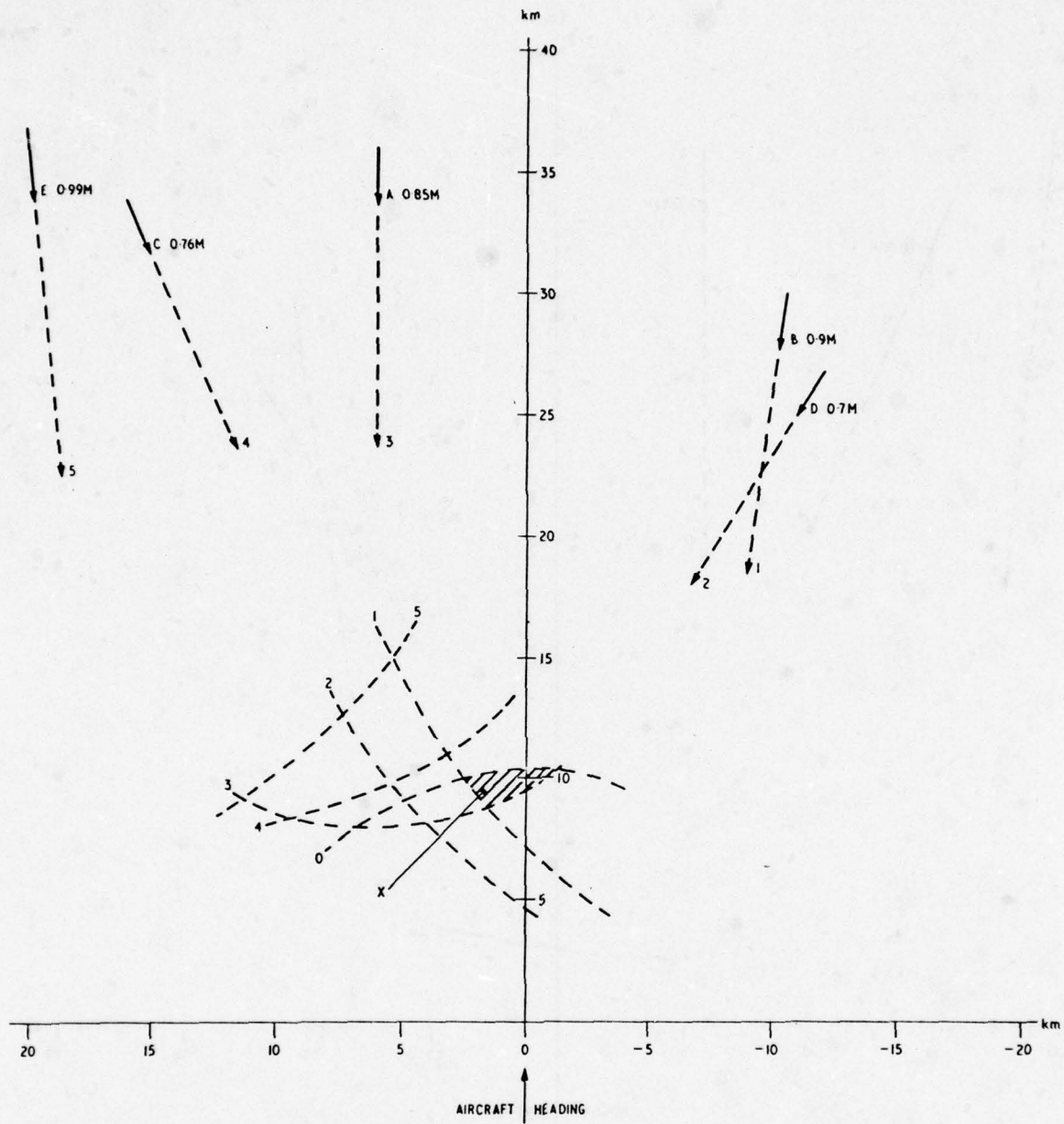


Figure 25 Visual identification plot

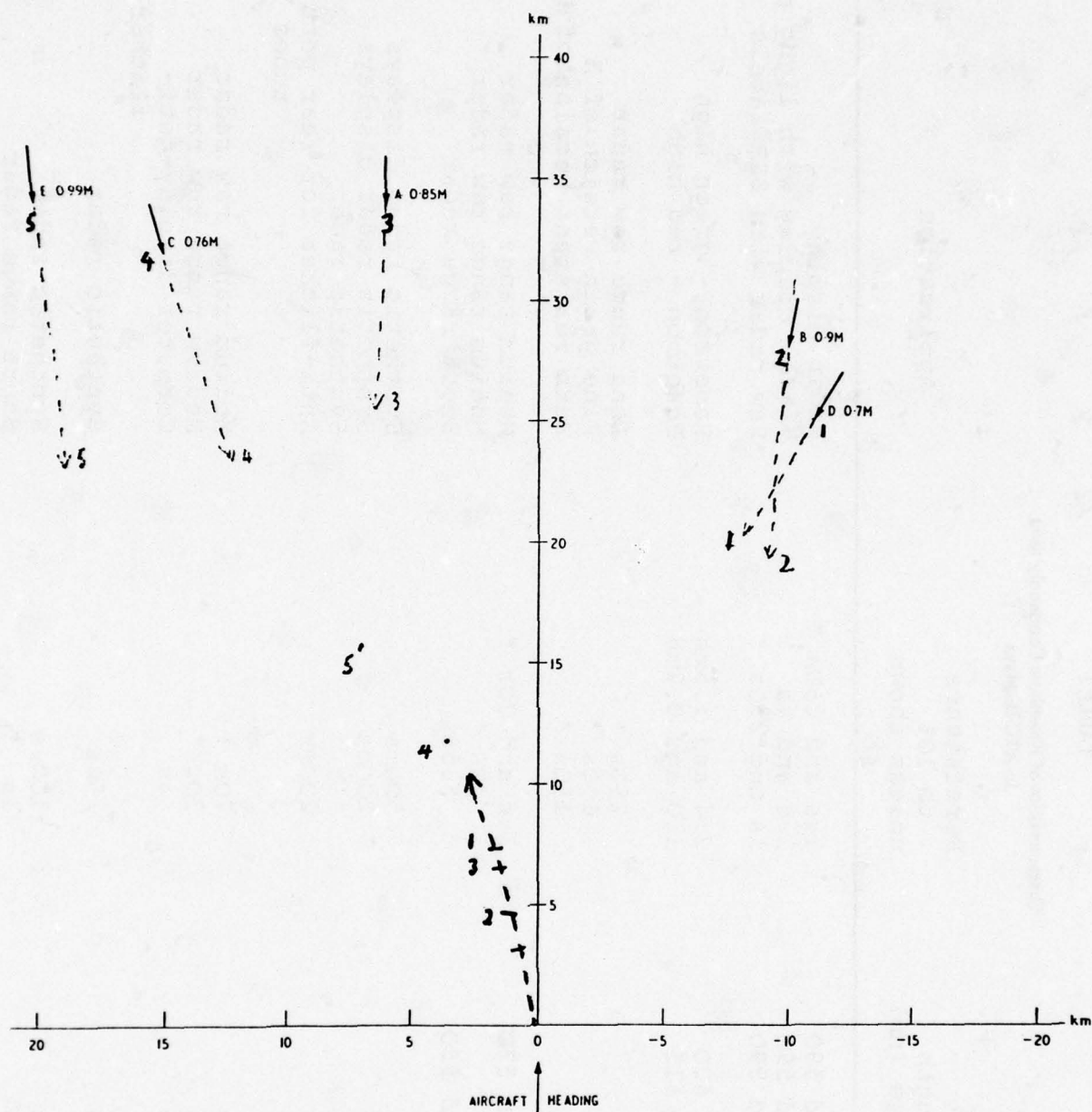


Figure 26 Target situation display

TABLE 1

Characteristics of Phosphors Commonly used
in ATC Displays

Type	Colour	Peak wavelength or range (nm)	Persistence to 10% unless shown	Application
B	B/O	450 and 590	1 μ s and 250s *	Radar display
B2	B/O	450 and 590	1 μ s and 4s	Visual display with light pen
B5	YG/O	520 and 590	1s and 250s *	Raw radar with SSR labels
C3	YG to R	530 to 620	2.4 and 1.5ms	Penetron - green high
C4	R to YG	530 to 515	1.0 and 0.2ms	Penetron - red high
H	O	590	250s *	Long range raw radar
H2	O	590	100s *	Fine grain version of H
H4	O	600	150s *	Burn resistant version of H
J	B/YG	450 and 520	1 μ s and 20s *	Medium range raw radar
J2	O	590	40s *	Medium range raw radar
J6	B/YG	470 and 550	3.5s	Short range radar
K	YG	540	500ms	Synthetic radar displays
K3	O	580	200ms	Synthetic radar displays
K8	YG	520	1s	Synthetic radar
K9	YG	520	200ms	Anti-flicker for rear port tubes
L	O	590	70s *	Medium range raw radar
L2	O	590	30s *	Medium range raw radar
L3	O	590	4s	Computer display-anti- flicker
P1	YG	520	25ms	Synthetic radar
P7	see type J			
P12	O	590	~100 μ s	Synthetic radar
P19	O	590	~1s *	Short range radar

TABLE 1 (continued)

Characteristics of Phosphors Commonly used
in ATC Displays

Type	Colour	Peak wavelength or range (nm)	Persistence to 10% unless shown	Application
P21	RO	400-700	~ 100ms	Synthetic radar
P24	G	500	400ns	Flying spot scanner
P26	see type H			
P28	see type K			
P31	G	530	3 μ s	High efficiency
P32	see type J6			
P33	see type L			
P34	G	490	~ 40 sec (variable)	Persistence stimulated with IR
P36	YG	470-670	250ns	Flying spot scanner
P37	B	450	300ns	Flying spot scanner
P38	see type L3			
P39	see type K8			
P40	YG	400-600	~ 100ms	Integrating phosphor
P42	YG	520	~ 100ms	Anti-flicker (P31 + P39)
P47	B	400	140ns	Flying spot scanner
Q8	see type P47			
S	see type P31			
Y	see type P34			

* Note: Persistence to 1% (applies to long component only of B, B5, J)

TABLE 2
Comparison of Solid State Displays

DEVICE	BRIGHTNESS mL	RESOLUTION	CONTRAST	COLOUR	MEMORY	DISPLAY SIZE	ELEMENT SIZE
PLANAR GA ASP	140		HIGH	655 m μ RED	NON VOLATILE		0.25 mm ²
SCANNED GA ASP	500	122 LINES		700 m μ RED	NON VOLATILE	CRT	
ZINC SULPHIDE DCEL	300 (MAX)	0.25 mm		580 m μ YELLOW / ORANGE	NON VOLATILE	35 ELEMENTS	1-2 mm WIDE
LED	1000 (MAX)		HIGH	565 m μ 690 m μ		40 x 60 ELEMENTS	5 mm (HEIGHT)
AC PLASMA	10-80	3 DOTS/mm	25:1	585 m μ RED/ ORANGE	NON VOLATILE	500 x 500 ELEMENTS	.05 mm ²
DC PLASMA	15	1 DOT / mm	25:1	585 m μ RED/ ORANGE	NONE	70 x 200 ELEMENTS	0.5 mm ²
LIQUID CRYSTAL	10,000 : AMBIENT			WHITE AND AMBIENT		100 x 100 ELEMENTS	25 mm ²

DISCUSSION

J. Wild

What reduction in storage is achieved by the use of the bi-arc technique for map drawing, and what sort of processing power is required to produce the map shown.

Author's Reply

The reduction obtained is obviously a function of the map complexity. Typical figures are 85 to 95% reduction in data storage. The work was done using an ICL 1903 in multi-access mode. No estimates have been made so far for the real-time computer power required.

J. Wild

I should like to make two comments: The first concerning Penetron displays. Today the resolution is as good as monochrome displays and the brightness adequate for operations rooms. The second concerning DC Electro-luminescent displays. It is now possible to obtain displays whose elements number an order of magnitude greater than the 35 given in this paper.

Author's Reply

The Penetron display is adequate for low to medium ambient lighting conditions. It should be noted that the Trinatron is now being used in weather radar displays and this tube may be even more attractive.

I agree to your second comment. The table given was produced several months ago based upon published data at that time.

D. Bosman

Could you report on the acceptance by the operator or pilot of the new display technologies, the new data presentation techniques and, in some cases, the ensuing implications for task structure?

Author's Reply

This is difficult to answer without going into a lot of detail. In general for the first example given, some operator feedback is being obtained, but it will be sometime before sufficient data is available for a meaningful analysis.

THE REAL-TIME TACTICAL RECONNAISSANCE DATA HANDLING PROBLEM

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SUMMARY

An important role for airborne reconnaissance is the location and identification of targets in near real time. Current technology has been compartmented into sensors, data links, processing, ground exploitation and finally dissemination. In the days of bring home reconnaissance, this segmentation of functions was appropriate. However, with the current emphasis on near real-time intelligence, this thinking has to be reanalyzed. A total systems approach to data management must be employed using the constraints imposed by the atmosphere, survivable flight profiles and jamming. This paper will analyze the target acquisition through classification tasks and discuss the machine processing and data screening techniques that are applicable. The data handling capabilities of an on-board operator and ground based image interpreter are compared. A philosophy of processing data to get information as early as possible in the data handling chain is examined in the context of ground exploitation and dissemination needs. Examples of how the various real-time sensors (screeners and processors) could fit into this data handling scenario are discussed. Specific unclassified DOD programs will be used to illustrate the credibility of this integrated approach.

THE NEED FOR RAPID RECONNAISSANCE

Since the Blitzkrieg type of warfare was successfully demonstrated in World War II, the mobility of ground forces has constantly increased. It is now possible for very large, well equipped, full spectrum, ground forces to overrun defenses and thrust from tens of kilometers to a hundred or more kilometers per day, obtaining and maintaining control of the entire area encompassed, or to rapidly deploy in preparation for an attack. Suffice to say the battlefield, as well as the domain of air operations, can be extremely fluid.

It is the prime purpose of tactical reconnaissance to provide the theater and the field commanders with the necessary information about the enemy's operational situation to successfully conduct operations, both air and ground, in such a fluid environment. Obviously, this information must be timely.

When the enemy has the prerogative and the opportunity to conduct offensive operations, the need for timely information becomes increasingly critical. The defense must effectively react while the opportunity is available or before it is too late and their capability to do so is overrun or otherwise negated. In this type of highly mobile warfare tactical aerial reconnaissance plays a vital role, being the most mobile of all capabilities. A reconnaissance aircraft can travel at a rate of 18 kilometers per minute or more, permitting it to reach an area of concern from a remote base in a few minutes. It can cover a substantial area of concern in a few seconds. The crux of the problem is to make the information, so quickly gatherable, useful in time for reaction. To date this has been effectively accomplished too infrequently.

Traditionally, airborne reconnaissance has been accomplished by a reconnaissance vehicle flying over the area of interest. A variety of sensors aboard the vehicle sense and record the reconnaissance information for subsequent processing, interpretation and reporting of the digested information. These functions normally occur upon landing at the reconnaissance base. The time involved in this total process, from sensing to reporting, varies from hours to weeks, depending upon the type of missions and the quantity of data sensed (the extent of the coverage and the resolution), and the type of information to be extracted. This time factor can be broken down into functions as follows:

Air Transportation - Time for the vehicle to return to base and land. (Typically 10 min. to 1 hour)

Ground Transportation - Time to transfer the recordings from the vehicle to a ground processing station. (5 to 20 min.)

Data (or Image) Reduction - Time to process the recordings into extractable form. (10 min. to 2 hours)

Target Detection and Location - Time to find probable targets/areas of interest in the total recorded take. (2 min. to hours)

Intelligence Interpretation - Time to interpret the recordings into applicable information. (5 min. to days, or weeks in the case of maps). This usually involves correlation with other information.

Reporting - Time for reporting procedures (Preparation, Dissemination). (A few min. to hours, days for maps)

The above time factors are typical or average values. They may be significantly less for some reconnaissance missions where the number of specific targets to be reconnoitered is small and urgency procedures can be applied throughout the cycle. For missions in which the information perishability factor is an hour or more, traditional capabilities are adequate to solve the problem. They will continue to provide the bulk of the reconnaissance and intelligence information obtained. However, for reconnaissance of more perishable, or more urgent targets, the normal reconnaissance-intelligence cycle must be drastically compressed or significantly changed into a real or near real-time reconnaissance capability in order to be responsive to a highly mobile threat.

The functions of target detection, location and interpretation normally involve the human eye and brain processes which are not amenable to significant time compression. Consequently, for near real-time operation, those reconnaissance jobs requiring substantial human study must not be undertaken or the

process will rapidly outgrow its required time frame. The amount of information for which the human is tasked should be no more extensive than that absolutely required for the primary purpose of the mission. Only answers to simple and precise reconnaissance questions can be expected from a human observer in real or near real time. It follows that real and near real-time methods should only be applied to obtain the minimum information essential to make a decision where rapid response is likely to be required.

The historical method of gathering data is with a film camera. A film/camera data rate of 10^9 is not uncommon. For the real-time case, a sensor data rate of 10^6 to 10^7 pixels per second as experienced in typical tactical scenarios. This pixel rate number is arrived at from convoluting the ground resolution, swath width and V/H necessary to adequately perform the tactical mission. The human in the interpretation task has a 10^5 data processing rate (Gardiner and Nicholson, 1971).

Because of the limited amount of information which a human can handle in real or near real time, and the tremendous amount of data which a sensor can acquire in real time, a human observer in the reconnaissance aircraft may well miss or overlook very important information which may not be quite as time sensitive as that of initial prime concern. For this reason, as well as for verifying the airborne interpretations, it is important that permanent recordings be made of all sensed information for more thorough assessment after return to base, even though the intent of the mission is one of obtaining a specific real or near real-time reconnaissance answer.

OPERATION ASPECTS OF REAL-TIME RECONNAISSANCE

The traditional reconnaissance information process cycle was broken into steps and defined. They are repeated here for convenience:

- | | | |
|----------------------------------|--------------------------------|-------------------|
| 1. Air Transport | 2. Ground Transport | 3. Data Reduction |
| 4. Target Detection and Location | 5. Intelligence Interpretation | 6. Reporting |

The use of a wide band data link makes possible the elimination of several of the above reconnaissance cycle steps and the possible reduction of the time factors of others. For example, if the data link can operate directly from the reconnaissance vehicle, while it is acquiring the information, and can transmit at the acquisition rate, then steps 1 and 2 above are eliminated. In addition, step 3 can be reduced by operating the recorder-processor in tandem with the receiver, at the information acquisition rate. Rapid film processing technology can reduce step 3 to under two minutes, under special conditions to as low as 10-15 seconds. Even if the reconnaissance aircraft cannot transmit while acquiring, a buffer storage can be provided in the aircraft to permit transmission when the aircraft reaches a position from which it can transmit. This will not eliminate step 1 but will reduce it considerably; step 2 will still be eliminated; and step 3 will be reduced as above. Step 3 can be reduced to zero by use of a dynamic display of the information instead of, or in parallel to, the recorder.

For steps 4, 5 and 6, the human is normally involved and reduction of time elements for these steps can only be reduced by changing his duties. The time required is a function of the area covered by the reconnaissance per unit time, the number, size and deployment of targets of concern, other target characteristics such as smoke, dust, or tracks, the ability to extract the pertinent information from the scene (clutter, contrast), the number of interpreters employed, the skill and experience of the interpreters, and the procedures used. The target/background characteristics (such as clutter and contrast) are always dominant factors.

Real and near real-time transmission of reconnaissance imagery can thus reduce the total time factor between acquisition of the reconnaissance and reporting to a matter of approximately ten minutes up to an hour or so. Wide band data transmission is thus most useful for information whose perishability factor is in this time range. However, this conclusion is valid only when the human's time factors do not dominate the equation. Otherwise, the process becomes swamped, quickly breaks down, and is useless.

For operation in a high jamming environment or line of sight conditions where a wide band data link capability may be unuseable, the same results can be achieved with a dynamic display for the reconnaissance crew in the reconnaissance vehicle and having them perform the entire process and report via a narrow band link. The reconnaissance cycle time is thus reduced to the time required for the reconnaissance crew to detect and recognize (interpret) the targets and verbally or symbolically report their findings. Within certain constraints, this can be a matter of seconds.

If the reconnaissance crew is delegated the authority to make strike decisions, it is now a reconnaissance/strike capability. This reconnaissance/strike process has been accomplished for many years for a limited range of applications and under restrictive conditions. The traditional forward air controller, operating in low-performance aircraft, is an example of the entire process which usually includes decision making and direct or indirect control (target designation) of strikes. Until recently, the principal reconnaissance sensor of the forward air controller has been the human eye, unaided or aided with various types of visual optical sights. In addition, a substantial amount of reconnaissance information has been collected visually by strike pilots as an adjunct, or in addition, to their primary strike missions. In these cases, the process has been in real or near real time although no reconnaissance sensors nor displays of pictorial reconnaissance information, per se, were necessary. However, the conditions of operation have been restricted to daylight and good visibility.

Sensor technology now permits the reconnaissance capability, as well as that of the forward air controller, to be extended to nighttime operation and/or conditions of visibility well beyond the eye's unaided capability. In addition, depending on the scenario, the near real-time reconnaissance or forward air controller capabilities may be accomplished from high performance aircraft. In these cases the target rate, clutter and contrast become more and more important. While much work is progressing to model and quantify the effect of the physical variables on the human performance of detecting and recognizing targets at real-time rates, the variables are so complex, numerous and interrelated that the problem

cannot be generalized. The remainder of this paper will discuss techniques to assist in the real/near real-time performance of sensors/humans to perform reconnaissance missions and the operational limitations of such techniques.

One of the prime functions of aerial reconnaissance is to maintain periodic surveillance of a large area of concern to alert the commander to enemy activity or movements. As these missions must, of necessity, be flown at high altitudes in order to survey wide areas, line of sight to the receiving station (ground or airborne) can be achieved. Use of directive and tracking antennae reduces the susceptibility to jammers not directly or nearly in the line of sight. Only an airborne jammer nearly in the line of sight can effectively jam the receiver and thus the transmission.

For the surveillance mission, where activity is the prime factor of interest, targets need not be recognized as such. Just changes or movements or other unique features of detected objects need be observed. Of course, the objects detected must have a high probability of being of military significance, or this relationship must somehow be deducible. For this purpose cues can be used. The most readily available cues are:

1. Motion (MTI Radar)
2. Change Detection (Radar)
3. Electromagnetic Emissions
4. Heat Emissions (Infrared Sensor, weather permitting)

Obviously the degree of normal, non-military, activity of the surveyed area must be relatively low. A convoy of military vehicles on a busy highway will be detected but only supplemental information will differentiate them from normal civilian traffic. On a little used secondary road, however, the appearance of many moving objects would be cause for alert.

In any case the decision of where and how to react will probably require a specific reconnaissance mission to determine, through recognition, what the motion or activity really means. The most useful purpose, then, of a surveillance mission is to highlight points or small areas for more detailed coverage, as well as to provide alert warning. As this mission is accomplished from high altitude and covers large areas, radar, either MTI or side looking-synthetic aperture, or more desirably a combination of both, can provide an all-weather surveillance capability of wide areas for activity indication and alert purposes. The information, either raw or partially processed, may be linked to the ground via wide band data link and automatically processed into imagery for manual read out. If provided in digital form, the information may be automatically compared to information from a previous pass of the same area in a digital change detector with all changes superimposed on the radar map. Such a radar surveillance capability may be augmented with electronic reconnaissance and/or infrared for the detection of targets with those specific characteristics. For an analog system the human is required to look at imagery and, depending on the situation, could soon take so much time as to obviate the advantages of real-time transmission. Automatic digital change detection can overcome this limitation, and provide the necessary movement information within the allowable time.

For detailed examination of specific points, small areas or routes which have been highlighted by surveillance missions, or other sources, as requiring closer scrutiny, specific reconnaissance sorties are needed to provide the necessary information. Today's state-of-the-art in automatic target identification is not sufficiently advanced to preclude the need for human recognition of targets on which to base strike decisions or tactical employment commitment. This is not to say that exigencies of the situation may not require action based on such a dearth of confirmatory information. The operational situation may be critical enough to "blast every blip in sight" but in the absence of the need for such desperate measures it seems fair to assume that commanders will require more positive identification, based upon recognition or at least reliable classification, before major commitment of resources. Automatic classification techniques, discussed later, are under development, but accuracy, completeness and low enough false alarm rates for operational reliance have yet to be flight demonstrated and proven.

As humans must, as yet, do the recognizing of targets, this must predominantly be done by virtue of the shape and size of the target. Today's radars or microwave sensors do not provide sufficient resolution for recognition of most tactical targets by their shape. Their resolution is improving (with complications) but many unanswered problems, such as specularities, susceptibility to electronic counter-measures, etc., need resolution. Thus the primary recognition sensors (other than direct eyeball) must now be electro-optical or infrared imagers which present visual-like information to the human. Operating in the optical wavelengths (less than 300 micrometers), these sensors are susceptible to atmospheric degradations. They cannot operate through clouds so, in the presence of cloud cover, they must be used below the ceiling. Also, due to atmospheric haze, sensor performance improves as the distance to the target is decreased. Sometimes (in heavy fog) they are totally ineffective.

The atmosphere factors, plus the current trend of flying very low to survive in today's high threat environment, dictate that this type of reconnaissance mission be performed at low altitude.

Low altitude operation over hostile territory poses two very severe problems for wide band data links. Such links require line of sight from the transmitting aircraft to the receiver. If the transmitting aircraft is at low altitude, terrain masking prohibits the maintenance of line of sight to a ground receiver. The receiver, either as a relay or as the interpretation station, must be at high altitude. Such a receiver is highly susceptible to jamming by very unsophisticated means. Its overall operating cost is high and it is a lucrative target for direct attack. Even if the receiving station employs highly directional antennae tracking the transmitting reconnaissance aircraft, if the jammer is anywhere in the vicinity of the reconnoitered target area, then the jamming can only be overcome by one of the following:

- a. Recording the reconnaissance data for transmission when the reconnaissance aircraft proceeds

away from the jammers (if it climbs to high altitude then it can transmit directly to the ground, as does the surveillance mission, and a relay is not required but the highly directional tracking receiving antenna is).

b. Transmitting a moderate information band width, over a very high transmission band width digital data link while using sophisticated digital processing techniques to overcome the jamming. This restricts the transmitted information band width to, at best, several hundred kilobits per second (a high altitude receiver with directional tracking antenna is still required).

c. Observing the target areas and interpretation of the target situation by the reconnaissance crew with direct or subsequent reporting over a narrow bandwidth, jam resistant (possibly secure), digital data link by voice, symbology, or very limited pictorial coverage.

CUEING AND AUTOMATIC SCREENING AND TARGET CLASSIFICATION

Cueing for the wide area surveillance mission has already been discussed. Use of autonomous cueing, screening or target classification techniques on specific reconnaissance missions would enhance the search capability considerably to accomplish reacquisition of targets which have moved, or to overcome positional errors in either the original target location or in the navigation. They may even provide some capability for finding targets of opportunity. If the cueing technique is automatic the reconnaissance crew or the ground interpreters are assisted in the search function (a function which the human does very poorly but machines can do well) and permits their concentration on the recognition and identification functions (which machines do poorly but humans do well). Several cueing techniques will be discussed below, along with their applications in conjunction with an identification sensor to provide a localized search/identification capability. These cueing techniques are highly target dependent. Specific unique target characteristics are used and false alarm (non-targets with similar unique characteristics) rates are constantly a problem. While clutter, without target-like characteristics, is no problem, in a highly target rich environment cues will only indicate the fact that there are a lot of targets or target like things. In this case, selection of a particular cued target for identification must be either manual or random.

CUEING USING THE IDENTIFICATION SENSOR

Infrared Cues. Under many conditions certain types of targets emit strong infrared radiation by virtue of their temperature/emissivity characteristics. These emissions may be detected at long range by a FLIR operating in the "wide" angle mode near the horizon, although target masking by terrain or foliage may be a problem. With a 20° field of view the sensor may be "panned" slowly across the forward horizon for the detection of such emissions. Upon detection the narrow angle of the FLIR may be employed, centered on the "hot spot" and closure employed until recognition. In the case of a downward looking infrared sensor, hot spots on the imagery automatically draw attention to specific points and their immediate surrounds. While hot spot cueing is inherent in an infrared sensor, it is not effective if a proliferation of hot spots appear.

Automatic Screening. Considerable work, with some success, has been accomplished on applying automatic screening techniques to analog video signals, especially from infrared sensors (both line scan and FLIR). Simple algorithms have been developed to detect targets, with the first iteration being on edges and lines characteristic of man-made objects and further refinement being made on size and geometry. The screener divides a FLIR frame or section of a strip of line scan coverage into small areas and indicates which of the smaller areas does or does not contain man-made objects. The further refinements discard such man-made objects as roads and large buildings. Detection probabilities on vehicles have been high, but false alarm rates are highly dependent on the background due to the fact that features of vehicles (size, aspect ratio, etc.) used in the screening process are the same as those of some non-vehicle man-made objects of no interest. The principal virtue of this technique is that, in real time, it automatically discards areas of a scene wherein the probability of there being a man-made object is low, thus improving search time by a human. However, in a highly cluttered urban scene very little is discarded, limiting the usefulness of this technique to rural or natural backgrounds. The screener output may be superimposed symbolically on the observer's display and/or record either in the cockpit from a FLIR or line scan sensor, or at the receiving station, to highlight those small areas where the probability of there being a target is high.

The USAF Avionics Laboratory is currently pursuing this technology for FLIR applications. The current progress represented by an average false alarm rate of less than 5% and a probability of detection greater than 90%. This performance is considered promising enough for us to go forward with an airborne version next year.

CUEING USING A SEPARATE SENSOR

Radar. If the specific reconnaissance aircraft has a radar capable of detecting military targets plus an MTI capability, it can provide cues on which to point the TV or FLIR sensor for recognition and identification or to mark the line scan imagery. The radar must be capable of acquiring targets at low depression angles but at moderate ranges (less than 10 Km) from low altitudes. It must be capable of detecting the same types of targets that the surveillance radar does in order to reacquire those which have moved in the interim. At low altitude operation at very low depression angles foliage masking becomes a severe problem in many geographical areas. This problem may be overcome by using long wavelengths (low frequencies) or combinations of two or more long wavelengths. Such techniques have been proven to detect military targets in heavy foliage. This radar need not look forward but can operate in the side looking, synthetic aperture, digitally processed mode. As it need only detect, not recognize, its resolution can be poor and it need not "map" the terrain, just provide the direction and range to point the identification sensor or mark the line scan imagery. At low resolution, bandwidth is low and cost can therefore be quite low compared to most radars. The TV or FLIR can then be zoomed in on the suspected target by virtue of approach and by narrowing the field of view with the operator concentrating on identifying, not searching. A finite number of false alarms can be tolerated as long as principal

targets of interest are detected and the clutter is not too great.

The Avionics Laboratory is currently flight testing a digitally processed, low frequency SAR radar, called IMFRAD (Integrated Multi-Frequency Radar). Preliminary results indicate the ability to detect tactical targets masked by camouflage and foliage from low altitude and from higher altitude standoff surveillance ranges. The IMFRAD radar information is processed on board the aircraft in real time and does detect both stationary and moving tactical sized targets. Because of the automatic processing (the radar detects only the metal vehicular sized objects) the IMFRAD type radar can be used to search large areas and cue a high resolution sensor for the final target classification.

Three Dimensional Target Classification. Recent experiments with a modulated, laser line scan sensor have indicated the possibility of a very discrete automatic target classification capability using phase information to very accurately discriminate specific military objects by virtue of their shape and height characteristics. Automatic, real-time classification of specific types of targets has been demonstrated with a high probability of classification and a low false alarm rate. To date, coverage of such a sensor has been restricted to no more than 20° from nadir so its applicability as a cue for human confirmation with a FLIR or TV in a high speed vehicle, or for very wide angle coverage, remains to be demonstrated. Its output can be directly applied to a downward looking sensor. In fact, being a line scanner, it has its own pictorial output in the reflectance domain as well as a three-dimensional image.

The Air Force is just embarking of a program titled Target Cueing and Classification Sensor. This program is designed to provide USAF with a real time, airborne, target classification (recognition) capability for the low altitude, high speed, penetration mission. The sensor will be capable of obtaining three dimensional spatial information and classifying targets based on shape discrimination to provide a high probability of detection and a low false alarm rate. The system will process the scene data in real time, <0.1 sec, and provide the user with the target name and location with respect to aircraft position. The system (sensor and classifier) will fit within the aircraft sensor bay and a 34 series RPV recce nose.

This automatic target classification capability will provide usable reconnaissance information in real time for tactical missions. This is especially valuable against mobile tactical vehicles such as SAMs, AAA, tanks, etc. This system will have direct application in the TAC Quick Strike Reconnaissance and Strike Control and Reconnaissance missions as well as in conventional real-time reconnaissance. Since targets are classified and located in real time, information can be transmitted to the user over a low bandwidth data link. The cues will also alleviate the human saturation problem experienced with uncued high bandwidth imagery.

Multispectral Cueing. Use of two or more sensors or one sensor operating in more than one spectral band, or wavelength, can provide information which can help to discriminate targets from their backgrounds. This is particularly appropriate to camouflaged targets in which other, readily sensed, characteristics may be the same. A tremendous amount of research has been applied to spectral signatures and discrimination techniques. Under some conditions they work well. However, naturally changeable and variable background characteristics have compounded the programming problem and false alarm rates are frequently high. These factors have inhibited multispectral cueing as a singular technique. If used in conjunction with other cues it may improve detection accuracy and reduce overall false alarms.

CONCLUSIONS

Rapid mobility of modern military forces dictate two fundamental requirements for reconnaissance operations: timeliness and completeness. Timely targeting information is needed for command decisions and reconnaissance operations are incomplete unless information is accurate and available during day, night and all weather conditions. Timeliness and completeness are opposing attributes in that rapid access implies a limited quantity of highly selective data, whereas comprehensive coverage under diverse conditions, with a high probability of success, implies a large amount of data. An approach being taken by the USAF Avionics Laboratory to reduce this dichotomy is to employ technological advancements in sensor performance, automatic data processing, automatic cueing and classification sensors, and effective correlation and data handling techniques. In addition, a sensor or processing concept is not considered viable unless it is affordable and compatible with operational systems and concepts.

An example that illustrates these techniques is to use the foliage penetration radar to cue an identification sensor. The radar can fly at the low survivable altitude and cue potential targets. The radar can automatically point a FLIR to the target area. An image screener can then highlight the targets for confirmation by a human decision maker. The total data rates are high but the human has to only confirm the classification of the target, he does not have to search. If this is a reconnaissance mission then the image could be data linked. If the transmission were jammed, the data rate could be reduced to adapt to the jamming by sending only the screened targets. The key is that the data is transformed into information as early in the cycle as possible thus allowing maximum flexibility. For the example of target overflight the radar can direct the aircraft over the target area and a sensor like the Target Cueing and Classification Sensor can complete the reconnaissance task automatically without the human.

Some of these concepts may seem radical, but the problems are severe enough that one must begin to consider new approaches and technologies that allow real-time data to be managed and exploited in a timely manner.

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- Gardiner, F.J., Nicholson, W.E., April 1971, Data Management for Improved Tactical Reconnaissance and Multi-Sensor Application. Proceedings for the Symposium on Tactical Reconnaissance and Surveillance, Institute for Defense Analysis, Arlington, VA.

DISCUSSION

M.Stainsby

How is the figure of 100 kHz bandwidth for the human being derived?

Author's Reply

This data rate was derived from experimentation. I reference a journal article in my paper. This article discusses the 90-100 kHz human bandwidth in detail.

I.Mirman

What is aspect angle sensitivity to determining image identification?

Author's Reply

Currently all experimentation on 3D imaging has used downward viewing. Today we do not know the aspect angle sensitivity. We are initiating research to experimentally determine the sensitivity. Our goal is a slewable sensor utilizing this 3D processing technology.

TACTICAL RADAR FOR AIR DEFENCE

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SUMMARY

This paper describes a tactical radar system whose design is based on the wide use of digital data processing. These techniques have replaced analogue and manual techniques in many areas, notably those of communications and radar control.

In many respects there has been a shift away from the traditional approach of designing a radar and adding a data processing sub-system. In the AR3D system the radar, data processing and display and communications sub-systems have been designed together, with the data processing sub-system providing many control functions within the other two sub-systems.

This approach has resulted in the conversions from analogue to digital signals on input (and vice versa on output) being moved closer to the input and output devices themselves (e.g. the radar, displays, air-ground-air radio equipment) making the overall system predominantly digital in nature, with consequential improvements in reliability, simplicity in manufacture and ease of deployment.

The paper describes each main equipment set within the system, highlighting those features and facilities which are based on the use of microprocessors, special-purpose digital processing logic and high-speed internal data transmission, or which are under the control of the central data processing sub-system.

Particular emphasis is placed on the resilience of the system to fault conditions, and on its flexibility both in a fault environment and when configuring the system to meet different operational requirements.

1. INTRODUCTION

1.1

The ever-increasing availability of sophisticated aircraft systems has re-emphasised the need for flexible and effective radar systems. Many of the countries requiring these systems have complex territorial environments, and this situation demands radar systems which embody all the features normally expected in strategic systems, but in tactically transportable packages.

1.2

Plessey Radar has developed a set of tactical radar systems modules to meet this demand exploiting the full potentials of available systems and hardware technology.

1.3

The Plessey system, incorporating a long-range, three-dimensional, surveillance radar (the AR3D) with its own high-speed signal processing, provides a high level of data processing, enabling fast presentation of essential information. The system comprises transportable modules, which in different configurations meet a variety of defence requirements ranging from forward command posts handling fifty aircraft tracks to complete system networks containing sector operations centres handling hundreds of tracks. Stations are linked by digital and voice channels to produce an air defence sector network having a high degree of tactical mobility, flexibility and resilience.

2. THE AR3D RADAR

2.1

A general view of the AR3D radar is shown in Figure 1. The radar provides long range coverage for early warning (500km range on 15m² target), combining mechanical scanning in azimuth (including a 'fast slew' facility) with frequency scanning in elevation, giving heights on all detected targets on every rotation of the antenna.

2.2

The mean power of the gridded klystron transmitter is 100kW but pulse compression techniques allow the use of a peak power of 1MW, (see para 2.5), this low peak power giving consequent benefits in simplicity and reliability.

2.3

Scanning in elevation is carried out by applying a swept-frequency signal to the vertical slotted waveguide feed array, a 30° swing in elevation being obtained by a frequency variation of approximately 140MHz.

2.4

A feature worthy of particular note is the ability to tailor the coverage of the radar by modifying the start frequency of the sweep. Using this technique it is possible to tilt the elevation coverage under computer control so that the high-energy transmission normally reserved for the low angle cover can follow the terrain, thus making more efficient use of the power of the radar in mountainous areas or for use in ECM situations.

2.5

The signal received by the antenna is amplified and then split by means of filters into overlapping signal processing channels. After conversion to second IF each channel is pulse compressed (to 0.1 us in the lower channels) using acoustic surface wave equalisers.

2.6

Each channel is then processed through a video quantiser and moving window target detection system, giving primary plot statements which give range, bearing and elevation. This information is transferred to the plot processing software in the computer system.

2.7

Digital MTI, with coverage controlled via the computer system, is provided in the two lower channels as standard.

2.8

Also under computer control are the first and second thresholds, circuitry providing plot overload protection, clutter elimination gates and the switching on and off of the processing of each elevation channel. This latter feature enables channels subject to jamming to be inhibited if necessary in particular azimuth sectors, eliminating possibilities of system overload due to extremely high plot rates.

2.9

Other significant facilities include a Jamming Strobe Extractor to estimate the elevation and azimuth of jammers, and the Jamming Influence sensor which estimates the effective range of the radar a jamming environment.

2.10

An on-mounted IF antenna, IFF interrogator and secondary plot extraction system provide complimentary secondary radar facilities.

3.

DISPLAY CONSOLES

3.1

Information is presented at Plessey Series 9 Autonomous Display Consoles (Figure 2), which are situated either in mobile cabins or remotely up to 500 metres from the main convoy in bunkers or other shelters. Each display console contains a number of display modules providing various facilities, controlled by a micro-computer-based Display Control Module (DCM).

3.2

The DCM is based on a DEC LSI-11 processor card, with which are associated peripheral interfaces, a special bootstrap for loading 'down-line' from the main processor system, and memory cards including a 'dual-ported' memory from which the Plan Position Indicator (PPI) is refreshed by direct memory transfer. The effect of the special memory and interfaces is to give the LSI-11 an effective power in the DCM role equivalent to that of a PDP11-34 using more conventional memory.

3.3

Refresh of the PPI is carried out via a Graphics Module (GM) which accepts simple commands output from the refresh store and uses them to set spot positioning and write characters and vectors. Each character is constructed from a number of short straight lines or 'limbs', the average number for a typical character being around 23, giving characters of very high quality. Average writing time for a character is around 3 us, and for vectors 64 us for a screen diameter. These writing times enable complex display presentations to be provided, particularly useful where map information is concerned. Uniformity of brightness and dim : bright ratios are maintained by the use of constant-rate character and vector generation, and the digital display file specification means that large characters and picture expansion can be obtained without the degradation associated with analogue expansion techniques.

3.4

The Radar Module (RM) converts radar video signals for display as an 'overlay' to the graphics information. Digital techniques are again widely used, with radar range and radar centre offset being controlled by the software within the DCM.

3.5

The Indicator Module (IM) which contains the CRT offers a very high writing speed and good linearity. The deflection coil driver uses a high-efficiency printed coil giving a fast spot settling time (around $7\mu\text{s}$ for a screen radius) and a positional accuracy of 1%. A contrast enhancement screen reduces specular and diffuse reflections considerably, giving a high contrast picture even in normal room lighting conditions.

3.6

Tabular information is displayed on two Electronic Data Displays (EDDs) (Figure 3) which use 512 x 512 line gas discharge panels (commonly known as 'plasma panels') as their display media. The main advantages of this type of display over a conventional CRT are the self-refreshing nature of the panel display, the screen 'flatness' and the considerably smaller depth required. This latter factor is particularly important in a mobile system where space is at a premium.

3.7

Each EDD is overlaid by a Touch Input Device (TID) formed from an array of intersecting infra-red beams. The TID enables each EDD to be used as a programmable keyboard, and this capability is fully exploited in the operational facilities of the system.

3.8

The console is also equipped with a Rolling Ball Unit for the input of positional information and a small alphanumeric keyboard for use in data entry (e.g. for flight plans), together with communications control panels appropriate to the particular system requirement.

3.9

Information of a more static nature (e.g. detailed ground maps, maintenance information) can be displayed on an Ancillary Information Projector (AIP) mounted in the top of each console. The AIP uses 35mm roll film, each roll providing up to 1000 individual frames, with electronic frame counting being provided.

4. COMPUTER SYSTEM

4.1

The main processing system contained in each of the modules with data processing facilities (i.e. the radar processing and control cabin, display cabin and communications control cabin) is based on the PM 1150 ruggedised processor manufactured by Plessey in California. The main element of this processor is a PDP11-34 processor card supplied by Digital Equipment. The PDP11 was chosen as the basis for this equipment for many reasons, a major one being the wide availability of peripherals, interfaces and software, both from DEC itself and from many other suppliers.

4.2

A ruggedised mounting box and power supply are used, with special arrangements for handling signal and power cables, and other than the processor cards and certain memory elements the rest of the processor configuration is designed and manufactured by Plessey. Peripherals are also specialised with a rack-mounted control terminal, ruggedised disc drives (Vermont Research Corporation) and a floppy disc system.

4.3

The dual processing system (Figure 4) in a typical display cabin, supporting six display consoles, provides a total of 176K words of core memory and 100M bytes of disc storage. Each radar processing and control cabin and communications control cabin is similarly equipped with computer equipment.

4.4

When the cabins are connected together, a complete computer network, containing typically six to fourteen PM 1150 processors, is set up using high-speed digital links to interconnect the processors. Data paths are duplicated, providing for automatic re-routing of data in the event of failure of a primary path. Figure 5 shows a typical computer network.

4.5

Interconnection between the computer systems at different stations is provided by a communications network using duplicated 2.4K bits/second data links. The software provides for routing of messages to particular consoles, operators or stations, including multiple destinations.

5.

DATA PROCESSING FACILITIES

5.1

Distributed digital data processing has a greater influence on system facilities than has previously been the norm. From the radar through to the communications system, digital control is used in almost every area.

5.2

The high-speed primary radar video processing logic, itself basically a special-purpose digital processor, is set up and controlled in real time from the main computer system. In this way many of the radar facilities such as electronic tilt, the digital MTI system and various thresholds in the plot extractor can be set up either under operator control from any display console or automatically under software control, to give quick response to situations such as ECM and other environmental factors.

5.3

Once the primary and secondary radar information is output by the plot extractors, it is used to create tracks by automatic initiation. The software in the main processing system is designed to provide computer assistance to operators by performing routine tasks and by giving quick access to a large amount of information. The emphasis is on computer assistance rather than automation; the system provides a flexible and comprehensive tool for the operator to use, rather than trying to do his job for him. Computer assistance is provided to a wide range of operational tasks, including track recognition, evaluation of threats, selection of the appropriate reaction, fighter interceptions, strike missions and recoveries, flight plan processing and association, and many others. Integral simulation facilities are provided for operator training and for facility evaluation.

5.4

The facilities provided to the display consoles are extremely flexible and designed for simplicity in use. Information is provided in a variety of forms on both the labelled radar or plan displays and the electronic data displays. Most information may be displayed on either type of display at operator request.

5.5

Of particular note is the use of general-purpose console equipment, with functions being assigned under software control. This allows an operator to perform his duty at any console, and to move to a spare console if equipment at his current console location fails.

5.6

High-resolution digital maps are displayed on the plan displays, with an increasing level of detail being shown as the display range is expanded under software control. Display parameters may be changed from metric to imperial units by operator selection, and the plan display may be centred on an area of interest either by operator selection or directly under software control.

5.7

The Touch Input Devices (TIDs) which overlay the EDDs provide a flexible keyboard facility. Most data can be amended directly by touching the appropriate item in a tote display and then inputting the new value; conventional input sequences are used only for the longer multiple value inputs, and in these cases only the inputs which are legal at any one time are presented to an operator for selection, thus significantly reducing operator errors.

5.8

Point-to-point communications and intercommunication facilities are also under software control; this is described in more detail when the overall communications facilities are considered, in Section 6.

5.9

Comprehensive data recording is provided, with variable speed replay and analysis. Logging of both technical and operational parameters enables the performance both of the station and the operational personnel to be monitored.

5.10

The data recording facilities are linked to a voice recorder which records the communications activity at the consoles. On replay, voice and data recordings can be synchronised to provide a comprehensive real-time representation of the recorded situation.

5.11

The software is highly modular and uses the total computer complex as a virtual machine. Many software elements are duplicated in different processors to provide reconfiguration capability under failure conditions, and the data base is also duplicated across the station. Software is written in a high-level language, RTL/2, and is structured and documented using structured plain code (SPC), a technique designed to give clear documentation minimising the need to use flow diagrams which are expensive to produce and maintain.

6.

COMMUNICATIONS

6.1

The point-to-point and intercom. facilities, both within and between stations, are provided by a special type of processor - controlled telephone exchange. This exchange, called the voice switch system, is under direct control of the main processor system, thus making its facilities available to users via the display and input devices in the consoles. In particular, calls are made using the TID and EDD to make selections from subsets of the overall directory. When an operator 'signs on', the system automatically gives him fast access call facilities to other operators associated with his job. The system directs calls to subscribers either by name or by job title, wherever they are located in the sector, and provides facilities such as conferencing, multiple levels of priority and call-back listings. Calls made to job titles who are not currently 'signed on' are automatically routed to the appropriate immediate superior of the person called.

6.2

The voice switch system also handles calls to external agencies such as airfields, missile sites or higher echelons, and interfaces with field telephones and field exchanges. Figure 6 is a diagram of a typical voice switch system.

6.3

The air-ground-air communications system makes extensive use of digital techniques, both to reduce cabling and to provide flexible operational facilities. The frequency synthesisers of the VHF/UHF transmitters and receivers are remotely controlled from the users' consoles via a microprocessor-based multiplexing system. In addition, the relationship between channel number and frequency is set up under processor control and can be displayed as one of the information totes at any system console.

6.4

As a standby point-to-point system, and to provide access into the public telephone network, a microprocessor-based PAX is provided, giving a comprehensive set of facilities.

6.5

At the lowest level of communication, each console and system module (including power generators) is fitted with a technical intercom. system using self-powered headsets which are carried by technicians. This system aids in setting up a station or in other situations where prime power is unavailable for the other communications facilities.

6.6

A teleprinter network is provided to link stations and external agencies such as airfields, the meteorological service, civil flight plan and service and so on.

6.7

Communications channels between cabins, stations and to external agencies are carried by a variety of types of communications bearer. Between cabins within a station, and to remotely deployed consoles, balanced line transmission of both data and voice uses mobile point-to-point equipment (UHF, troposcatter etc.) or (in more static environments) private or leased lines.

7.

CONFIGURATIONS

7.1

A minimum station configuration comprises four mobile units - the antenna, the transmitter cabin, the radar-processing and control cabin and the mobile power supply. This can be enhanced by display and communications cabins as required to meet the system application. A station can be increased in capacity by adding more cabin modules to handle larger numbers of tracks and provide more display consoles, the only practical constraint being that of response time across the extended station configuration.

7.2

The AR3D antenna unit (Figure 7) consists of a compact, circularly polarised linear feed array positioned at the focus of a simple parabolic cylinder reflector. The reflector is of lightweight design and folds easily, being

raised and lowered hydraulically, allowing for rapid and easy deployment.

7.3

The Transmitter Cabin (Figure 8) contains low-power swept pulse generation equipment, a coherent high-power S-band transmitter and a wideband receiver amplifier.

7.4

The Processing and Control Cabin (Figure 9) contains equipment necessary for receiver signal processing, primary plot and height extraction, secondary plot extraction, digital MTI, radar monitoring and control, a dual processor system and up to five labelled radar display consoles with associated communications facilities. Two remote transportable consoles may also be connected to this cabin module.

7.5

The Display Cabin (Figure 10) contains a dual processor system and six labelled plan/radar display consoles with associated communications facilities.

7.6

The A/G/A and Communications Control Cabin contains a variety of equipment depending on station role and user requirements. A typical cabin is shown in Figure 11. It is fitted with UHF/VHF/HF air-ground-air communications equipment, the main communications voice switch, the PAX, voice recorder teleprinter and equipment and dual processor system handling point-to-point data communications via modems.

7.7

A point-to-point Communications Bearers Cabin, when required, contains the microwave or UHF multi-channel point-to-point terminals. Troposcatter or other terminals may also be used.

7.8

The Workshop Cabin provides a self-contained workshop capability which is immediately available in the field providing each station with a limited but autonomous repair and maintenance facility.

7.9

A typical Reporting Post (Figure 12) would use the minimum station configuration providing automatic initiation and tracking of 60 to 100 tracks, with limited communication facilities.

7.10

Adding a communications cabin provides full air-ground-air communications and enables the capabilities of the data processing system to be exploited, giving control facilities in the form of 6 - 12 computer-assisted interceptions or strike missions.

7.11

The capacity and facilities of the station may then be improved by adding display cabins, and stations such as the Sector Operations Centre (Figure 13) can be configured.

7.12

These various types of station may also be integrated into complete systems (Figure 14), providing overall air defence co-ordination facilities over one or more operational sectors.

8. MOBILITY AND DEPLOYMENT

8.1

The system modules are designed to be transportable by road, rail and air. Road transportation is by four-wheeled trailer or by semi-trailer and the modules are designed within normal international road and rail transportation envelopes. Air transportation is by C130 or C160 aircraft. Figure 15 shows a Processing and Control Cabin with 5 displays, mounted on a semi-trailer.

8.2

Multi-trans running gear, a type of low-speed mobiliser, is used to assist in moving the modules on and off the trailer, rail vehicle or aircraft. This equipment is adjustable in height to match a wide variety of loading platforms.

9.

AVAILABILITY

9.1

The system is designed to provide an extremely high level of availability, by minimising the effect of individual equipment failure and by providing comprehensive built-in test facilities.

9.2

The radar Built-in Test Equipment (BITE) allows monitoring of parameters and waveforms within the radar processing sub-system to isolate faults down to PCB level. Digital and analogue highways connect all major sub-units within the radar to a BITE operating station positioned at the Technical Monitor Console (Figure 9) and the status of major equipments, determined on a GO/NOGO basis, is continuously displayed on a mimic diagram.

9.3

The computer equipment is duplicated within each cabin, with facilities such as the display consoles and radar input interfaces being accessible to either of the processors. In the case of the communications control cabin, a hot standby processor is provided within the computer system. The overall computer network is able to accept failures of single and multiple computers while continuing to provide useful operational facilities.

9.4

Defensive programming techniques are widely employed within the software making it robust even in situations of hardware malfunction. All hardware inputs are checked for validity, and data packets transferred between software tasks are re-validated by the receiving task.

9.5

The overall network of computers, peripherals and displays is routined by the software to detect hardware malfunctions. A comprehensive software diagnostic package is also provided to assist in fault-finding and equipment repair.

9.6

The use of digital techniques reduces dramatically the amount of cabling required, particularly in the communications sub-system, and allows alternative control paths to be utilised in the event of failure of the normal path.

9.7

A comprehensive alarm-monitoring facility is provided with an equipment alarm panel placed in a prominent position in each cabin. The alarms from the power generators and unmanned Transmitter Cabin are also routed to these panels.

9.8

A Workshop Cabin can be provided with each station, allowing field repair to be carried out. A particular feature of the workshop cabin is the display console test harness which has access to the videos and timing signals from the live system, allowing display modules to be tested using live data and thus minimising the use of special test equipment.

10.

CONCLUSION

10.1

This paper has described a flexible and sophisticated tactical radar system incorporating many features not usually associated with tactical systems. The system is characterised by an extremely wide use of digital data processing, giving major improvements in availability, ease of deployment and level of facilities. The distributed computer system enables a wide variety of operational requirements to be met using a standard range of equipment modules.

ACKNOWLEDGEMENTS

The author wishes to thank the Plessey Company Limited for permission to publish this paper and to acknowledge his many colleagues whose efforts contributed to the paper.

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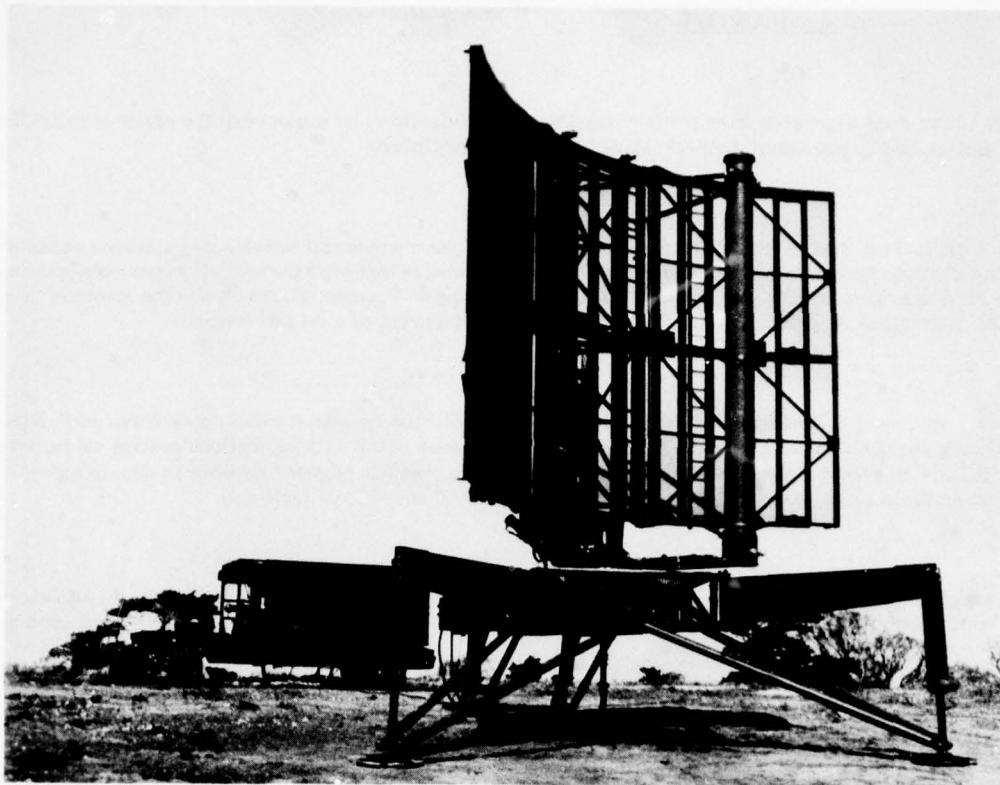


Fig.1 Photograph of AR3D radar system



Fig.2 Photograph of typical series 9 display console

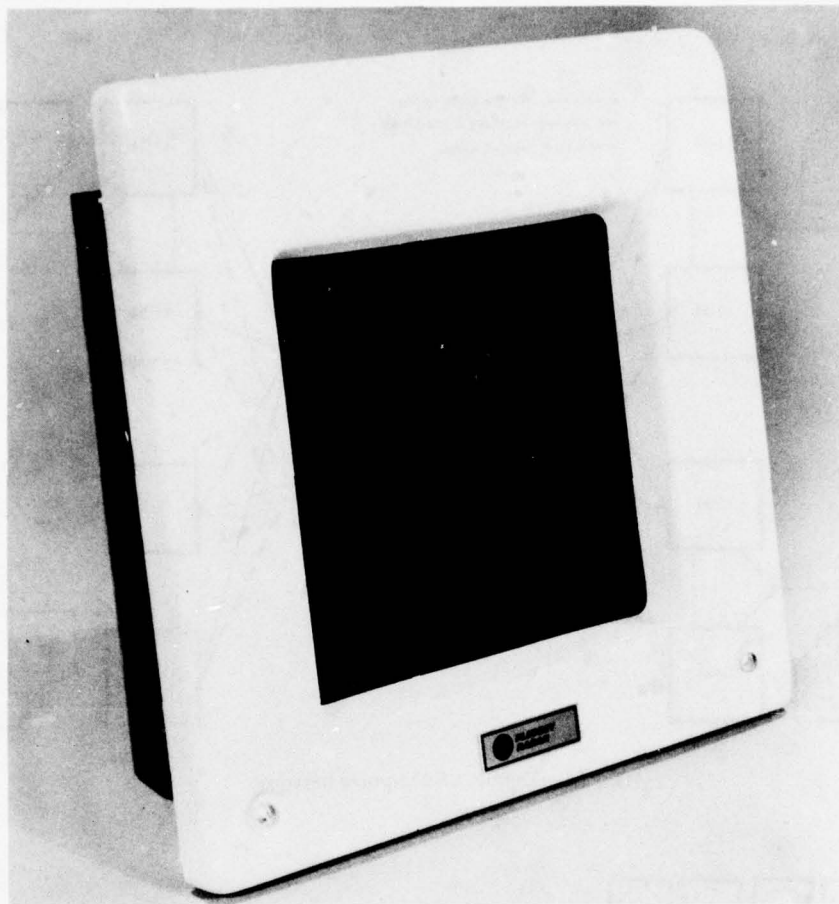


Fig.3 Photograph of EDD assembly

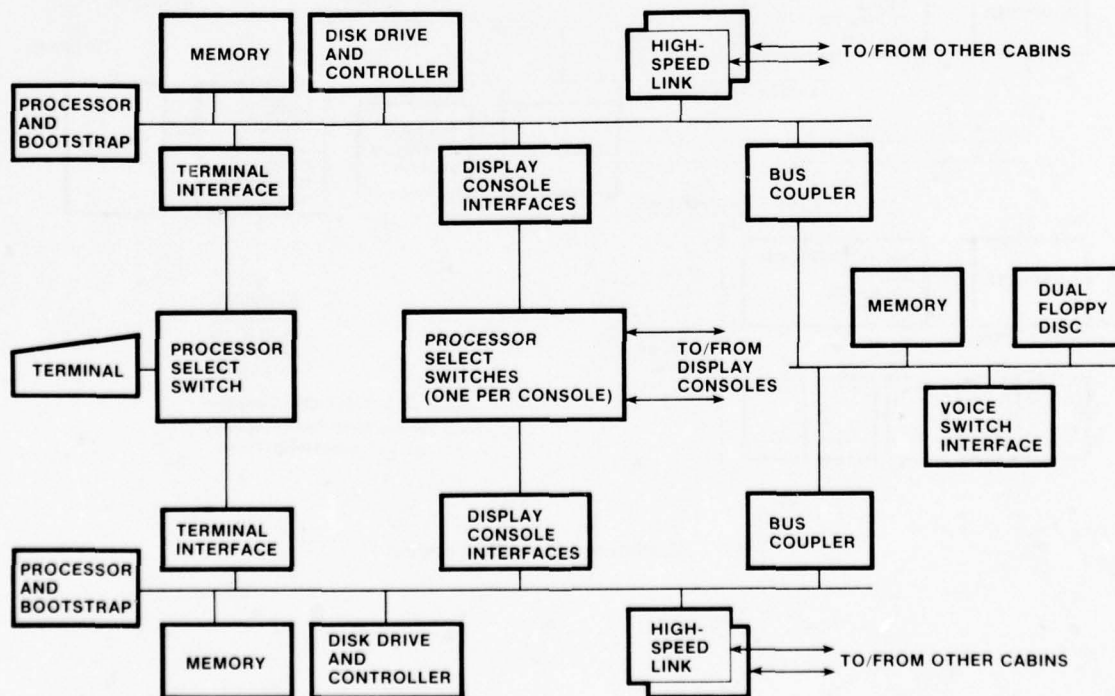


Fig.4 Diagram of display cabin dual processing system

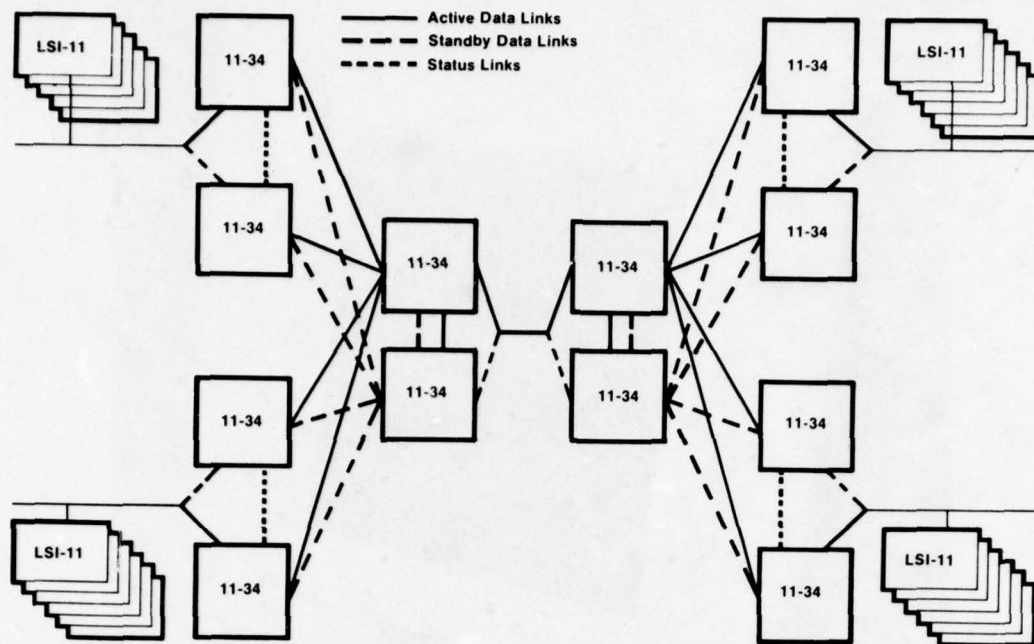


Fig.5 Diagram of computer network

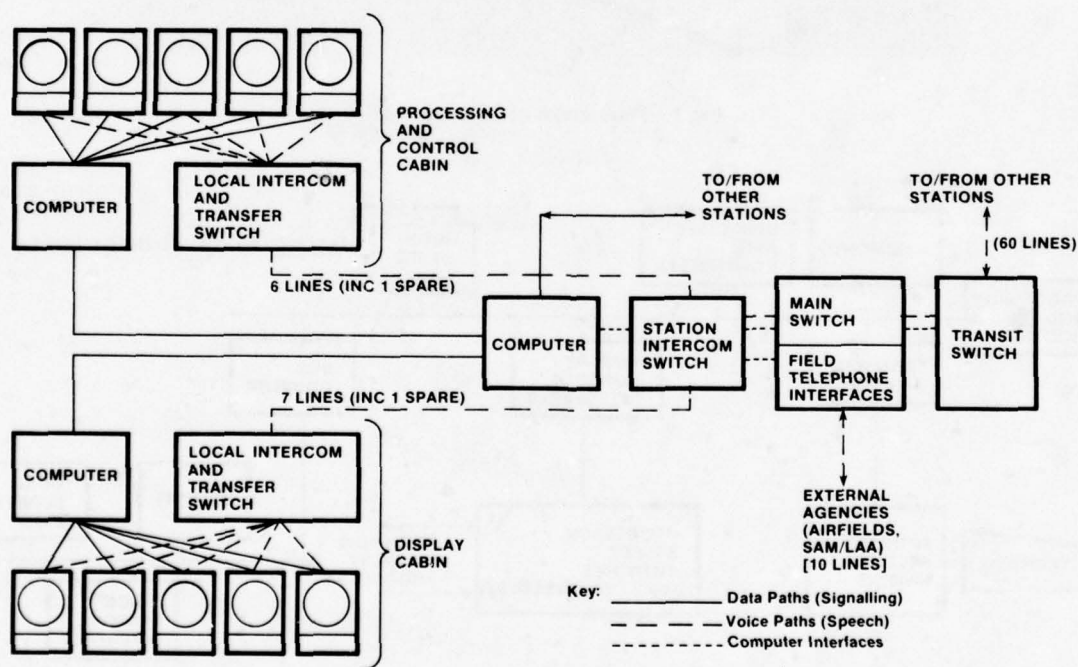


Fig.6 Diagram of voice switch system

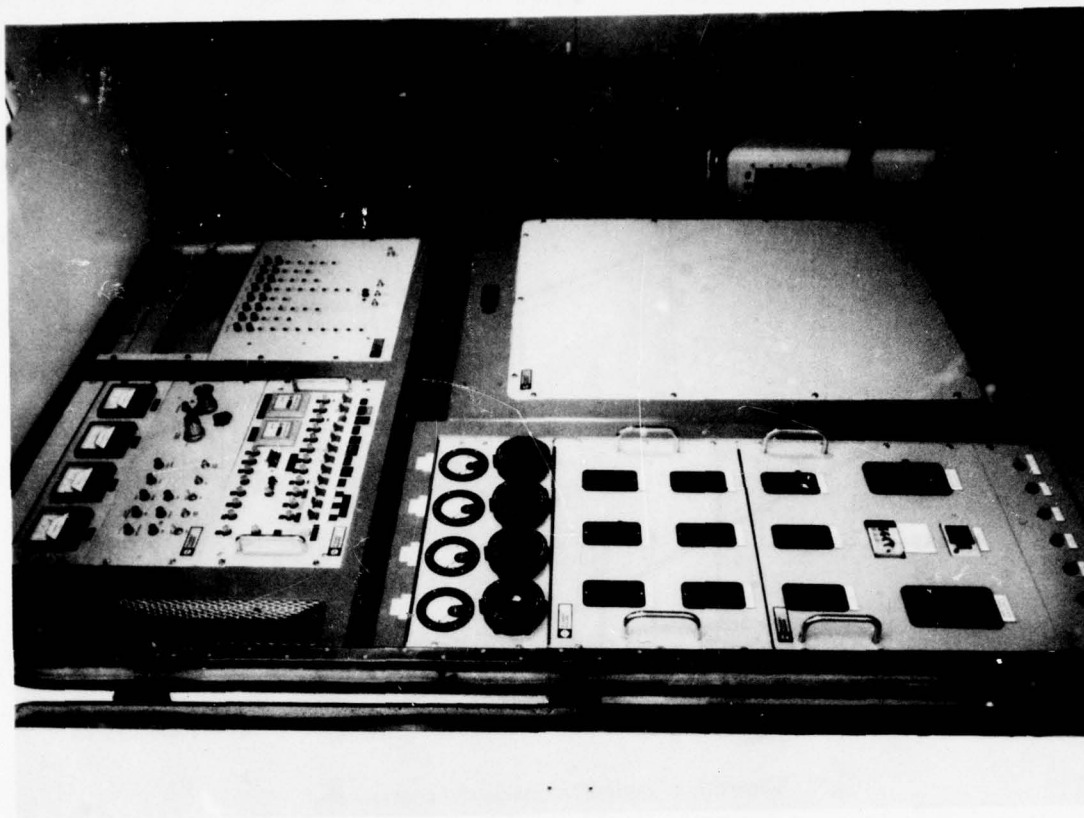


Fig.8 Photograph of AR3D transmitter cabin



Fig.7 Photograph of AR3D antenna

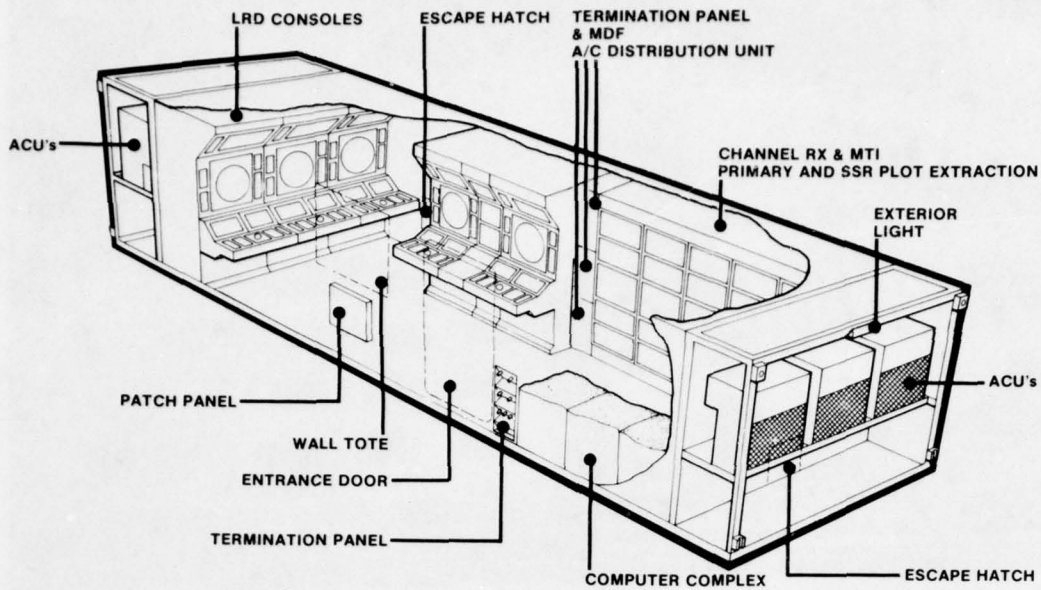


Fig.9 Schematic of typical processing and control cabin

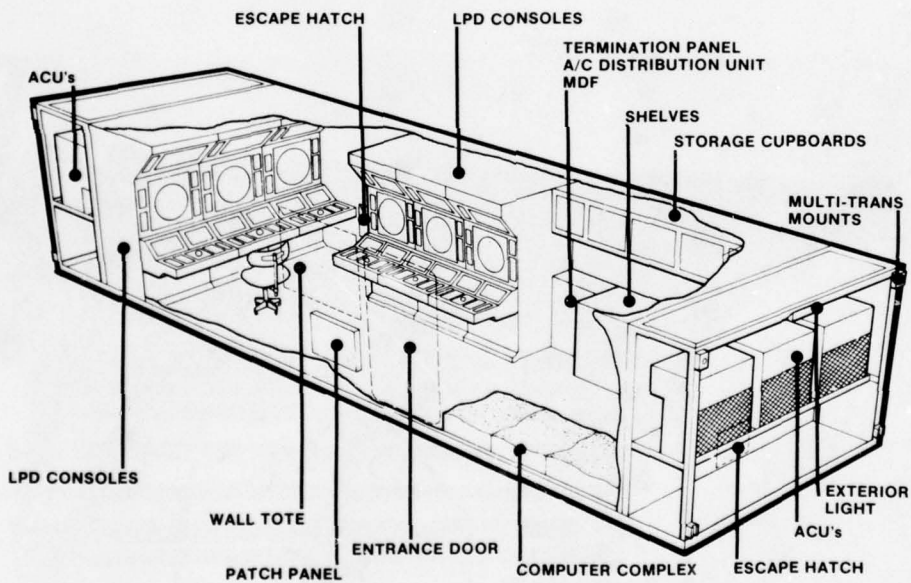


Fig.10 Schematic of typical display cabin

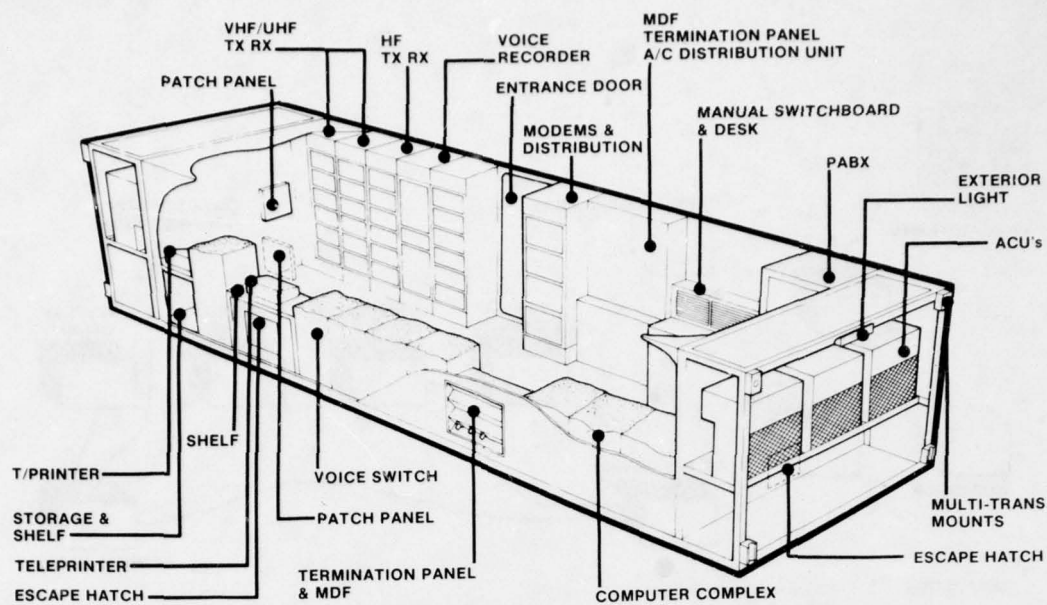
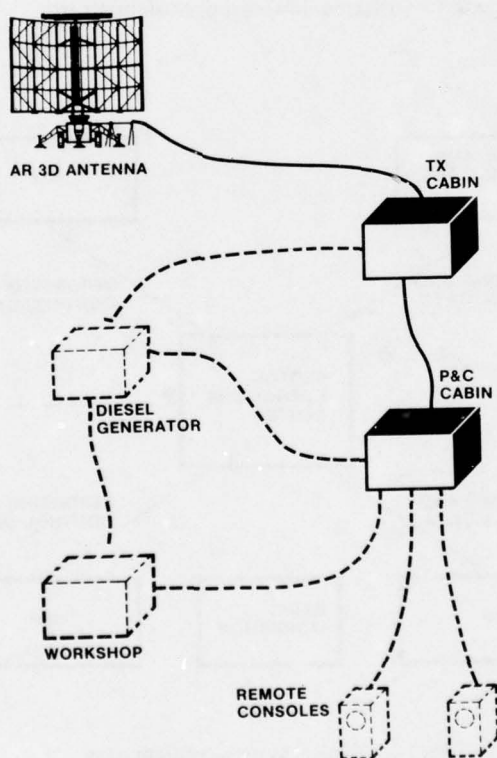


Fig.11 Schematic of typical A/G/A and communications control cabin



CAPACITIES: Operator Consoles — 5 (+ 2 Remote)
Track Capacity — 120

Fig.12 Diagram of reporting post

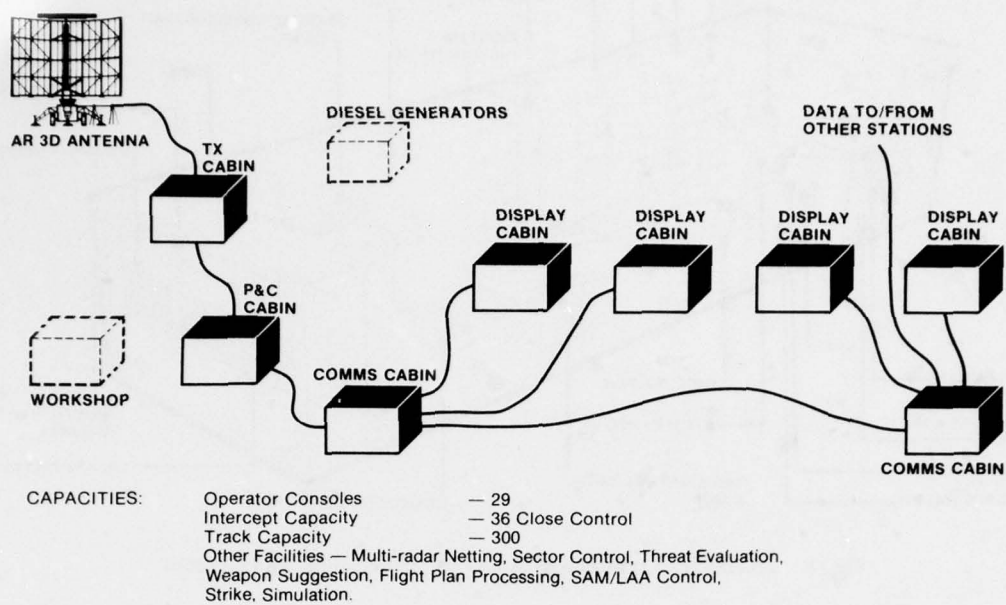


Fig.13 Diagram of sector operations centre

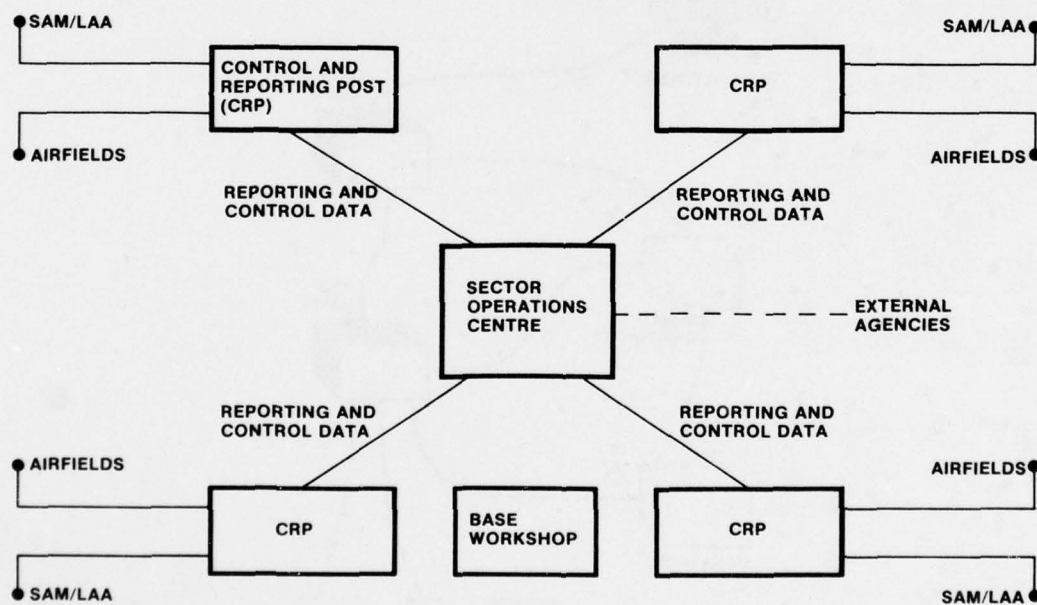


Fig.14 Typical system configuration

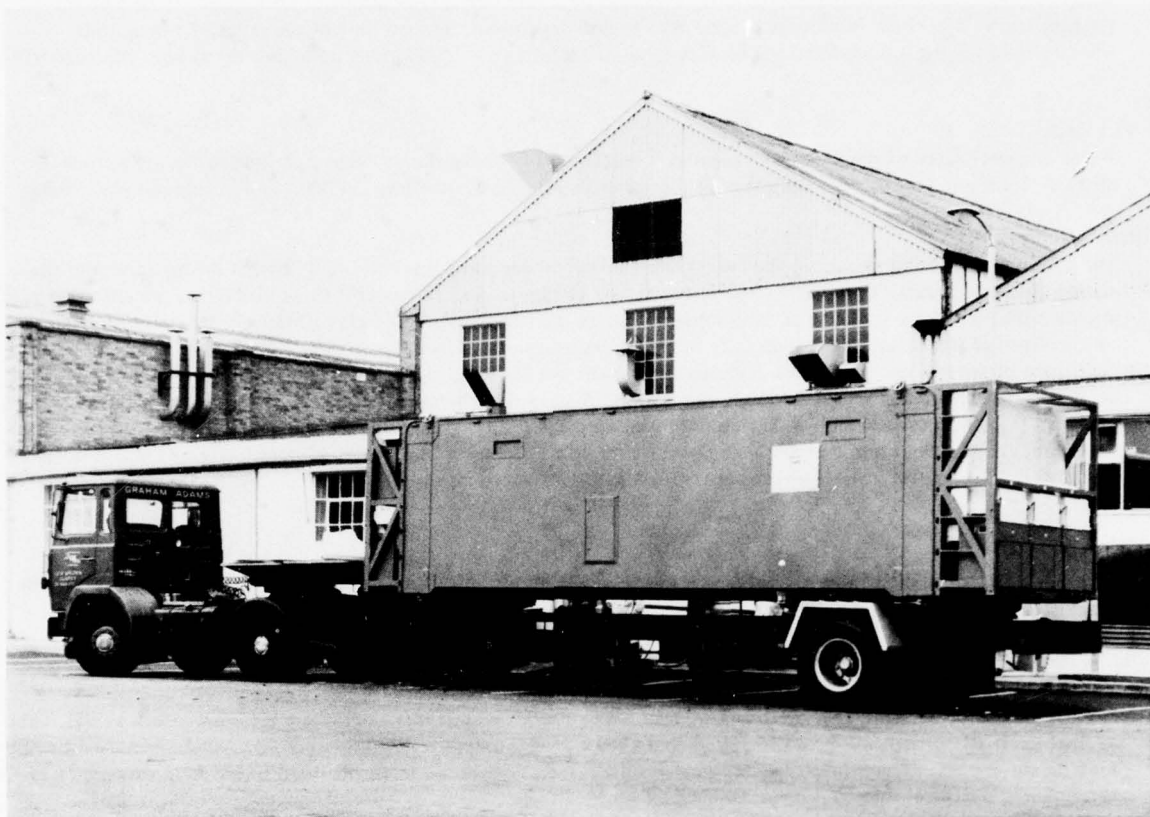


Fig.15 Photograph of cabin on semi-trailer

DISCUSSION

H.B.Driessen

You mentioned in your oral presentation an upper limit for the density where you attempt automatic initiation. Could you quantify this upper density?

Author's Reply

There will be a clutter density above which automatic initiation will not be attempted due to the large number of possible tracks that could be initiated. This density will depend on the scan time of the radar, the maximum velocity tracks being initiated and the total number of tentative (or acquisition) trails that the system can cope with.

G. Van Keuk

When you net radars on the data processing level you sometimes have the problem that the sensors are not ideally aligned. Have you studied the sensitivity of the various strategies against misalignment and inaccurate positioning.

Author's Reply

In a multiradar tracking situation, the two greatest problems are probably lack of any height information and the misalignment of radars. Both these situations will lead to bias errors. However if these bias errors remain reasonably constant over a sufficiently long period of time these biases may be estimated algorithmically by selecting straight-line sections of tracks, either from aircraft flown for that purpose or from targets of opportunity. It also appears that these biases will vary range and azimuth of the various radars and therefore the most practical solution will be to average the biases from several straight-line tracks. A second problem appears to be the time dependence of the biases so that their estimation will have to be repeated periodically. These algorithms can be run off line (not in real time) and can therefore be quite complex. We have investigated a linear least squares technique which involves a relatively large matrix inversion that has resulted in satisfactory bias estimations.

J.B.Tasche

Can you give information on the extra core space required by your using RTL-2 instead of MACRO-11 and also what is the extra program run-time?

Author's Reply

We have no statistically significant data on the efficiencies, but it would appear that between 30% and 60% extra memory might be needed. However, we find that very good programmers can produce RTL-2 which is as efficient as their good assembler. We have also found that a poor programmer often produces RTL-2 which is more efficient than his assembler. On run-time, we are not really able to distinguish between the operating system overhead and the language overhead since this is our first use of both of these.

J.B.Tasche

In the UK there is a well established standardisation for the use of Coral 66 for MOD projects. There are in existence a few Coral 66 compilers for PDP-11. Why not RTL-2 selected instead of Coral 66?

Author's Reply

Two factors are relevant to this particular choice. At the time the project was begun, the PDP-11 Coral 66 compilers were very unreliable (we benchmarked three compilers). We actually chose an operating system (MTS) before the language. Coral 66 was not supported under MTS, a very mature and reliable RTL-2 compiler was available so we used it. The operating systems which did support Coral 66 were not truly real-time and we could not accept the overhead.

A. Clearwaters

Concerning the security of your system, two points: Can you prevent unauthorised user from getting into the system? The common displays allow any format on any display. Are there any methods for controlling a low-level user from calling up and using supervisory formats? In other words, does the system enforce, through its formats, the hierarchal nature of a military system?

Author's Reply

There are certain limited features which prevent unauthorised users accessing the system, particularly from remote terminals. Formats are role-oriented in the way you describe. Many formats can only be accessed via a supervisory role.

IMPROVEMENTS IN THE MAN-MACHINE INTERFACE FOR DATA ACQUISITION, DISPLAY AND CONTROL

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SUMMARY

This paper discusses a method for improving the man-machine interface in civil and military data automation capabilities. The method combines existing hardware technology with innovative software features to provide an interactive capability responsive to the system user. Integral to the concept is the use of a touch entry device and a tabular display for message composition and entry. One or more tabular displays are used for the presentation of data forced to the position or requested by the user. Support software is discussed including the use of implied logic designed to facilitate the message entry process, branching logic to guide or prompt the user in formatting messages for entry to the system, and display logic responsive to the needs of the position.

Techniques for application of this technology to a real-time system like Air Traffic Control are described in detail. Potential application to other types of systems is identified. This paper concludes with a summary of benefits expected to be attainable through implementation of various aspects of the described method.

INTRODUCTION

In the past decade, tremendous progress has been achieved in hardware and software technology to meet civil and military data automation requirements. However, the ability of a system user to efficiently and expeditiously manipulate and utilize information derived from this technology significantly depends on the man-machine interface established for the system. In general, there is a continuing need to improve the technology of this interface in order to achieve benefits such as:

- Simplifying the message/command/data entry process;
- Reducing the incidence of input errors affecting both the stored data base and the resulting processing and display of essential information;
- Reducing the overall man-machine response times, not just the response times associated with internal computer processing;
- Tailoring of information displayed at an operating position to meet the needs of that position;
- On-line assistance in tactical and strategic planning; and,
- Providing a dynamic capability to assist in the training of system operators and users, thereby shortening the training cycle.

The purpose of this paper is to present a concept for improving the man-machine interface. This concept represents a merging of existing hardware technology with innovative software features to produce a more viable symbiotic environment, which is most useful in assisting or prompting the user in entering frequently as well as infrequently used messages into a system. An example of the applicability of this concept to a system like Air Traffic Control is presented as a way of illustrating the potential of this approach to improving the man-machine interface.

The concept was developed under the auspices of the Federal Aviation Administration (FAA), Systems Research and Development Service, as part of an overall plan for sector position design improvements. The intent of the plan is to provide additional automation at sector control positions in order to enhance the operation of the Air Traffic Control System and to increase productivity within controlled volumes of airspace.

An experimental subsystem incorporating the interactive capabilities described in this paper is currently under development as the first step to providing the additional automation. This subsystem, known as ETABS (Electronic Tabular Display Subsystem) is designed to replace flight progress strips and to simplify controller message entry in the Air Route Traffic Control Centers (ARTCCs). ETABS is expected to reduce the current manual and relatively intensive workload associated with flight data bookkeeping and updating functions.

The basic design of this subsystem has been demonstrated at the MITRE Corporation, Metrek Division, in McLean, Virginia. This design served as the basis for generation of the specifications for an Engineering Model to be installed at the FAA National Aviation Facility Experimental Center in Atlantic City, New Jersey. The subsystem will be evaluated in a simulated operational environment to assure that the design meets the operational requirements of the sector control team. The results of this evaluation is planned to be used for development of the production specifications for an operational system.

Potential application of the described concepts to other automation capabilities is discussed. This paper identifies those basic functions within generic systems most amenable to these design concepts. The paper concludes with a summary of the potential benefits expected to be achieved by improving the man-machine interface.

MAN-MACHINE INTERFACE PROBLEMS

The complexity of the message entry process is a fundamental problem with the man-machine interface. This can be attributed to the input devices used to specify data for entry to a system and to the software designed to support message composition. Most electro-mechanical input devices, such as keyboards, keypads and switches, are cumbersome to use and contribute to a message entry process which is time-consuming and error prone. A variety of software command languages, text editors, etc. have been designed to accommodate particular devices already selected for a system. However, more needs to be done to facilitate message composition by guiding or prompting the user through each sequential step in the message entry process. In addition, software tends to expand to meet increased operational requirements, thereby adding to the complexity of message entry.

This problem has been recognized over the years. In 1971, Culhane pointed out that ten input devices are used at the radar-controller position in the U.S. Air Route Traffic Control Centers (ARTCCs). He stated that, "while each individual input action is not necessarily difficult for the controller to perform, input actions are awkward, complex and cumbersome". In 1972, Parsons reported on some earlier studies of illegal (computer incorrect) switch actions taken during SAGE Air Defense exercises. Those studies found 12.5% of all switch actions to be illegal and that, "the number of illegal actions rose as the load increased on an individual operator". More recently, a study performed by Amato in 1977 showed that input error rates at supporting radar positions in two ARTCCs approached 25%. This confirmed previous studies indicating the same error rate at other facilities.

The presentation of information is another problem that needs to be addressed if the man-machine interface is to be improved. One aspect of this problem is that a mismatch (Hopkins, V.D...1975) occurs in the display of information in relation to the user's comprehension of that information. Hopkins rightly claims that, "a discrepancy between the information provided and the information used occurs in modern systems which contain more information than can be assimilated or displayed". There is little operator control over the quantity and the selectivity of information presented or displayed at most operating positions.

Response time is another area of concern and should include the time for system detection of input errors and the time required by the operator to correct these errors. It is often stated that, "the response time is the elapsed time, measured in seconds, between the completion of a user command and the receipt of a user reply" (Gardella, R.S....1976). In actuality, the total response time, from initiation of an input message and then entry, to receipt of an accept reply should be used as a measure of responsiveness. In most systems, this total time can be critical.

One additional problem with current interface designs is worth mentioning. This is the training required to operate and use a system. Lengthy training cycles are the vogue in many systems with a resultant cost in time and personnel. As Locher (Locher, J.P....1969) stated, "If it takes a lot of training and operating time to develop this capability (of using the interface), there are serious man-machine problems that should be promptly resolved".

Perhaps the overriding problem with the man-machine interface is the tendency of system designers to design systems so that the interface is computer oriented rather than user oriented. In most cases, resources are heavily committed to developing the mechanics of system operation, such as the architecture of the software, the communication facilities, and the data base storage techniques. Too little attention is committed to an interface design to facilitate the use of the system. This needs to be changed if the full capabilities of data automation are to be realized through a synergism of hardware, software and man-machine interface technology.

INTERACTIVE DESIGN

Most of the problems described earlier can be alleviated by upgrading the interface capabilities at the operating position itself. This can be done by providing improved message entry and display devices and by supporting these devices with local data processing. The basic technology for doing this exists today in the form of touch entry devices operating in conjunction with tabular displays, and the use of displays for data presentation. This approach is not new. In fact, some of the techniques described in this paper are based on consideration of the work performed in the United Kingdom (CAA Paper 77020....1976) and at EURO-CONTROL.

Touch entry is currently being used in a number of other systems and tabular displays are becoming more popular for the output of information from a central computer system. However, it is the combination of these devices plus localized data processing and special software features which shows the greatest promise of improving the interface. This combination can be used to tailor the interface to meet the needs of the position and beyond this, the needs of the individual operating the position.

TOUCH ENTRY

A touch entry device overlaying or operating with a tabular display simplifies the man-machine interface. The selection of displayed data becomes a natural extension of the thinking process. The user can quickly and easily indicate to the system the selected data by merely touching a displayed field or item. This technique can be used for message composition and entry, to provide a rapid means of communicating with the host computer system, and to manage the display of information at the user position.

Two of the touch entry methods in use today are:

- Light beam overlay consisting of light emitting diodes (LEDs) in a phototransistor array creating an X-Y grid over the surface of a display.
- Pressure sensitive devices imbedded within the surface of a display - e.g., wires, acoustical "pads", thin tubes.

The LED method requires that an X and a Y beam be broken to enable the device to determine the location of the touch point. When a finger breaks the grid, light beams are interrupted. These interruptions are sensed by the associated transmit-receive pair. The address of the interruption point is then determined by the touch panel electronics and transmitted to the computer. It is not necessary to touch the display surface. The pressure sensitive method requires physical contact with the displayed data in order to select the data.

The disadvantage of existing LED technology is that the (flat) X-Y grid requires a somewhat flat surface in order to achieve maximum utilization of a display surface. The common inexpensive CRT introduces a noticeable parallax problem while flat surface displays tend to be expensive. The disadvantage of the pressure sensitive method is that imbedded devices tend to diminish viewing ability of displayed data under low lighting conditions and cause reflection problems. In addition, continuously touching the display surface causes finger smears and, depending on the display, deterioration of the surface itself.

Additional research is necessary to improve the touch entry/display combination. However, the current success in the use of this technique is evident in several applications. In particular:

- A pressure sensitive acoustical method of touch entry is used at the University of Vermont to communicate with PROMIS (Problem Oriented Medical Information System).
- A LED method of touch entry is used at the University of Illinois to communicate with PLATO, their Interactive Computer Aided Instruction System.

DISPLAYS

One or more tabular displays can be provided at each operating position to:

- Serve as an interactive display for message composition in conjunction with a touch device and software features as discussed below, and to provide a means of displaying solicited and unsolicited messages from the computer.
- Serve as a data display for the presentation of information selected for display through the interactive display, or forced to the position, or used as a reference point for action initiation.

The two most attractive choices for an interactive display are a CRT and a flat panel matrix display. Because curved surfaces of CRTs can cause greater parallax problems, their use with LED touch entry devices requires careful attention in human factor and engineering designs. In addition, the depth of the tube makes console integration difficult in terms of accessibility to the operator.

Flat panel technologies - e.g., gas discharge, LEDs, liquid crystal matrix, are still in the developmental stage although the gas discharge method, in the form of plasma displays, is being used today. However, a flat panel display is preferred for many applications as the interactive display because of console packaging considerations and minimum parallax problems if the LED type touch overlay is used.

A number of display devices are available for use as the data display. Selection of an appropriate device is dependent upon the particular application and the human element. The prime considerations are display capacity to meet operational requirements, console packaging arrangements to promote readability of displayed information, and of course, the legibility of the presentation.

The display configuration is determined by the requirements of the operating position. Two display/touch techniques are possible:

- The direct touch whereby all areas of display are touchable. However, if large quantities of data are to be presented, the size of the display presents a "reach" problem to the operator.
- The indirect touch whereby a call-down technique is used to access data on a large display surface. This requires one additional touch to cause the display of the referenced data into the interactive area prior to initiating an input action.

Conceivably, the interactive and the data display can be the same physical display unit. However, in most cases, the interactive display is better suited as a stand-alone unit. In this case, the data display can be one or more physical display units of varying size(s).

LOCALIZED DATA PROCESSING

The cost, flexibility and packaging arrangement of a software/firmware driven micro-computer lend themselves to application at a user position. Direct assistance can be provided through software and firmware in the composition of input messages and in the selection and control of information presented on tabular displays. Data base files can be stored within the memory of the local computer to facilitate rapid call-up of information not presented on the display. A computer at each user position can interface directly with a host computer system or can be tied to a front end processor serving as a concentrator for the transmission of messages between the host and each localized computer.

SOFTWARE

Software resident in a computer at the operating position offers a high degree of flexibility to support the man-machine interface. Alternatively, some functions can be hard-wired (firmware) - if the response time requirements so dictate. The software should be designed to provide three basic functions:

- Permit a dialogue between the operating position and the host computer system for the purpose of requesting information, updating a data base, initiating network activities, etc.

- Format and display the information to be presented at the position.
- Provide a means for local (manual) control or management of information displayed at the operating position; for example, shifting of information from one area of a (data) display to another area, deleting displayed information no longer needed, or rearranging/reformatting information to gain a different perspective of the displayed data.

While common software can be implemented for each operating position, the use of adaptation tailors the operation of the software to meet the needs of the position or even the desires of the individual currently manning the position. Adaptation, in the form of tables generated by support software and stored within the operational software, can be used to support message entry, display, and management functions. It can provide the flexibility to change the operating characteristics of the software without changing the software itself; it can specify how and where information is to be presented on any display surface; it can maximize the use of the interactive display for message entry; and it can support each of the basic software functions.

Message Entry Function

Integral to the interactive display/touch entry concept is the use of menus, branching logic, and implied logic to support the message entry function. Composing a message for input to the system can become an extension of the thinking process when the operator touches displayed information presented under software control. Each of these features is discussed in the following paragraphs.

Menus - Menus can contain lists of message (type) identifiers and data necessary for each message type. Each item in a list can be positioned on the interactive display at one or more touch points depending upon the number of characters required for each item. In general, three types of menus can be adapted for each operating position:

- Tailored menus designed to meet the operational requirements of each position.
- Standard menus designed for universal use at all operating positions.
- Real-time generated menus to support a particular entry sequence as defined by the previous input selections. This type of menu can also result from real-time alteration of an adapted tailored or standard menu.

Since the contents of each menu can be presented under software control, the selection of message data can be syntactically correct, thus reducing the incidence of format errors in messages composed for input to the system. A standard keyboard should be made available to enter messages and data not available through a touch menu.

Branching Logic - Special software branching logic can be used in conjunction with menus to guide or prompt the operator in message composition. This logic can control the presentation of menus in hierarchical fashion if more than one component or field of data is necessary to complete a message entry sequence. When an item - e.g., message type, is touched in one menu, the next menu in an adapted sequence can be displayed to permit operator selection of the next field of data. This process can facilitate the message entry process and can assure the logical correctness of messages input to the system. It has the added advantage of teaching the user the format and coding of the message entry sequences.

Branching logic can facilitate correction or reinitialization of a previously composed message. In most cases, a message entry sequence can be designed to permit selection of additional or alternate fields of data after the message has been composed, but not yet input to the system. In most systems of today, the entire message composition process must be reinitialized in order to correct a field entered in error. The use of branching logic with touch entry can simplify correction of an incorrect field.

Implied Logic - Further simplification of the message entry process can be achieved through use of special software logic keyed to the display of information on the interactive display. This information can be the result of previous processing of data or the condition of a certain event. It can also exist in the form of an indicator alerting the operator to a situation requiring his immediate attention. Touching the displayed information can imply an action which can result in automatic generation and input of a special message. In other words, the system would respond based on the conditions that exist for the item selected. For example, an input action can be implied when the operator touches a displayed critical action indicator. The system can respond by displaying additional data associated with the critical action indicator without interfering with other activities such as message composition in process.

Implied logic can also be used to initiate an action to update information displayed on the data display, to direct an information message to another operating position, or to accept a message addressed to the position.

Display Function

Special display logic can provide the flexibility for matching display output with the needs of the individual operating the position. To a certain extent, this logic caters to the problem of "information presented in a wrong form for the man to understand and interpret in relation to his tasks", (Hopkins, V.D... 1975).

This logic can perform the following basic functions:

- Extract subsets of data from stored data files and format this data for display according to adaptation in effect for the operating position. It can respond to simple touch entry requests to present additional sub-sets of data from the same file entry, or to reduce the quantity of information presented. It can also provide for easy call-up of the total set of data available for an entry.

- Permit use of a "scratch-pad" area of the display for presentation of memory jogger types of notes selectable from special tailored menus. This action is similar to the current use of a pencil to annotate hard-copy output.
- Change the contents of a data menu based on new data entered through the keyboard.
- Respond to display management input actions affecting only the display of specific information at the entering position - for example, Delete, Move, Re-sort.
- Support the indirect display/touch technique used in system's requiring the display of large quantities of information.

APPLICATION TO AIR TRAFFIC CONTROL

Various aspects of these concepts can be applied to a variety of systems heavily dependent on the man-machine interface. The ETABS developmental effort currently underway by the FAA is an example of the application of these concepts to a system like Air Traffic Control. ETABS is expected to simplify the message entry process and to provide a means of displaying pertinent flight and non-flight information - e.g., meteorological data - on tabular displays at each sector position. ETABS is designed to guide the controller in composition of messages for entry to the system; to relieve the controller of the time consuming burden of handling flight progress strips, thereby permitting more time for tactical and strategic control functions; and, to provide a method for annotating displayed data similar to the current use of a pencil to mark flight progress strips.

The following paragraphs describe in detail the application of the Interactive Design concepts to ETABS. This application represents the initial capability to be incorporated within the ETABS Engineering Model for testing and evaluation.

ETABS HARDWARE CONFIGURATION

The basic ETABS configuration will consist of a network arrangement within each ARTCC whereby a micro-computer at each sector position is linked with a mini-computer through high speed communication lines. Peripherals to the mini include magnetic tape drives and bulk storage disk packs. ETABS has been specified to operate as a subsystem to the Central Computer Complex (CCC), or independent of the CCC if necessary. (The CCC is a multi-processing computer system supporting radar data processing as well as flight data processing.) Hardware redundancy will be provided to assure continuity in ATC operations in case of failure.

The two display types designated for each sector position are:

- A data display divided into areas containing information output by the CCC or requested by the controller - i.e., flight information similar to data currently output on flight progress strips, weather data, altimeter data, miscellaneous information.
- An interactive display divided into areas containing data necessary for controller interaction with the system - i.e., input menus used for message composition, responses to previously entered messages, a list of aircraft identifications (AIDs) used to access flight information displayed on the data display - indirect display/touch technique, composed messages prior to entry, special alert information, and flight plan data.

The flexibility of ETABS adaptation permits re-arrangement of data (areas) on each display type to meet differing operational requirements.

A touch entry device overlaying the interactive display will provide the means for rapid communication with the system. Touch points will be specified at a (limited) number of positions on the display to support actions consistent with the area in which the data is displayed. Approximately 256 touch points are considered sufficient to support the ETABS functions. A keyboard will be provided as back-up to the touch entry device for specification of message types and data not available through the interactive display.

ETABS SOFTWARE ORGANIZATION

A software interface package is required to interface the mini-computer to both the CCC and to each micro-computer. All flight data messages currently output by the CCC to the sector non-radar position plus additional messages to support ETABS functions, will be handled by this package. This software will perform message distribution; data base updating and provide certain fail-soft capabilities.

Additional software is required for the micro-computer to support the sector message entry and display functions and to interface with the mini-computer. All flight data information currently displayed at a sector non-radar position and most controller input messages will be handled by this package.

Adaptation - The commonality of the micro-computer software among all sector positions will be possible through use of adaptation tables. Adaptation will tailor the software to meet the operational requirements at each sector. As a minimum, adaptation will be used to specify the following:

- The position and format of information presented on the interactive and the data display. In ETABS, several format levels will be used to enable the controller to select the level or quantity of information (fields) to be displayed in the flight data area of the data display for each flight.

- The menus containing types and data to be used with the touch entry device. The adaptation for each menu will identify the touch point(s) for placement of each item on the interactive display and the branching logic to be used for each message entry sequence. Tailored menus will contain items to fit the needs of the operating position - for example, an altitude menu for a low altitude sector will list altitudes ranging from 050 to 240 feet. Standard menus will contain items appropriate for all sector positions - for example, a list of weather stations to be used to request meteorological information. Adaptation will be used to control the placement of data on real-time generated menus - for example, a list of fix elements to be used for a HOLD action, consistent with the filed flight plan route for the aircraft being placed in HOLD.
- Additional adaptation will be provided to control software modifications to designated menus used for multiple choice input actions. Displayed items will be cleared from a menu once a selection is made to prevent controller selection of items illegal for the particular message entry format. For example, the flight altitude for an aircraft may be specified as an altitude block. The first of two altitudes must be at a lower flight level than the second. Touching the first altitude will result in deletion from the menu of all altitudes below the selected altitude, thereby preventing controller selection of an incorrect second altitude for the altitude block.
- The branching logic to be used by the software to guide the controller in message composition. Message input formats will be specified and tied to displayable items on menus.

Message Entry Function - Two methods of identifying a particular message type will be used in ETABS:

- Direct action whereby the message type will be specified by touching the message identifier (mnemonic) displayed in an initial state menu.
- Implied action whereby the message type will be implied by touching a field of data not displayed in a menu on the interactive display. For example, a Flight Plan Readout will be implied and the Readout displayed when the Aircraft Identification (AID) is touched; an amendment to a flight plan field, e.g., altitude - will be implied by touching the field displayed in a Flight Plan Readout Area; a Handoff Accept action will be implied by touching the AID for an aircraft in handoff to the sector.

Branching logic associated with both actions will guide the controller by presenting, in sequence, menus containing data to be selected consistent with the message type format requirements. When data is touched in a menu and added to the message type displayed in a Preview Area, the next menu will be presented containing legal data selections necessary to complete the message entry sequence. When all fields of a message type are specified, the branching logic will return the initial state menu. The controller can then ENTER the composed message or restart the message entry sequence if an error was made in selection of a data field from one of the menus. The software will support total or partial message correction/reinitialization.

Two basic types of messages will be processed by the message entry function:

- System messages destined to the CCC. This will include all messages which can currently be entered at the sector non-radar position.
- ETABS special display management messages to be used by the controller to manage the presentation of data on the data display - e.g., MOVE, SORT, change format level actions. Special messages will be used to annotate fields of displayed data, e.g., pilot report at altitude, and to input control information, e.g., delivered clearance advisories, in scratch-pad fields within flight data. This capability is similar to the current practice of marking flight progress strips with a pencil. An additional feature will be an on-line capability to modify the contents of a tailored menu to suit changing operational conditions. The controller will designate the menu to be changed by touching an ETABS direct action message type, and will use the keyboard to enter the change to a touched location of a menu displayed as part of the direct action sequence. For example, standard clearance advisories displayed in a menu can be changed using this method.

Display Function - The following basic tasks will be performed by this function:

- Display of information received from the CCC or stored within the ETABS data base files.
- Support to the message entry function in the display of menus according to the branching logic, and in the display of composed messages in a Preview Area on the interactive display. Clear text will be displayed in a composed message wherever possible in place of message type mnemonics.
- Response to controller display management requests.
- Processing of updates to displayed flight data through automatic or manual modes of operation.
- Duplication of critical alert indicators on both the interactive and the data display to alert the controller to a condition requiring his immediate attention. Touching the indicator on the interactive display will cause the display of an Alert message into a designated area of this display. For example, a "C" indicator will be displayed with flight information on the data display and with the aircraft identifications of the appropriate flights on the interactive display. Touching the indicator or a special touch point in a designated Alert area will cause the display of a Conflict Alert Message for the two aircraft in a potential conflict situation.

Flight data will be displayed within the flight data area of the data display in separate lists - i.e., Departure, Information and En Route. The latter list will be further divided into sub-lists. The problem of constant fluctuations, as entries are added or deleted, will be minimized by treating each list and sub-list as a separate entity. Expansion or contraction of individual lists can occur without disturbing the remaining display.

DESIGN ILLUSTRATIONS

Figure 1 illustrates an earlier ETABS configuration used at The MITRE Corporation to evaluate some of the ETABS design concepts. It depicts the direct touch technique whereby the surface of both tabular displays is touchable. The assigned altitude of a flight plan is amended by touching (implied logic) the assigned altitude field displayed within the flight data on the lower display, touching an altitude displayed in an Altitude Menu, then entering the message.

The indirect touch technique is illustrated in Figures 2 through 7. The upper non-touchable data display shown in Figure 2 contains flight data presented to the sector position, and the lower touchable interactive display contains a list of AIDs consistent with the flight data displayed on the data display. In order to access flight data, the AID for the flight is touched causing the full flight plan (implied action) to be displayed in a Flight Plan Readout Area of the interactive display and the AID in the Preview Area. This is shown in the Figure 3 closeup of the interactive display. Figures 4 through 7 illustrate an input sequence for composition of a HOLD message. The action is initiated by touching (implied action) the coordination fix field. (A direct action HOLD message type was not adapted for inclusion in the menu shown on the right side of Figure 3.) The HOLD Fix and the Expected Hold Fix Departure Time are then selected by touching FRR and 2140 on subsequent menus. Figure 7 shows the composed message prior to entry to the system.

Figure 8 illustrates a possible design configuration to be used for testing and evaluation of the ETABS Engineering Model. It should be noted that the large (data) displays with a capacity of 16,000 characters meet the current operational requirements for the presentation of flight data at each sector position.

POTENTIAL APPLICATIONS

Various aspects of this interface technology have been applied at university research centers; e.g., University of Illinois (PLATO system), and in air traffic control systems in Great Britain and Italy. Other efforts are currently underway. It is not the intent of this paper to delineate these efforts. However, it might be useful to identify some of the functions within generic data automation capabilities where this technology is most appropriate. In particular, those functions heavily dependent upon a dialogue between the user and the computer are identified below.

Tactical Command and Control Systems

The basic elements of military Tactical Systems are data collection, storage and retrieval, display, analysis and decision making. The system must account for a wide range of factors such as the current battle situation, enemy intent, and force status. Users at various nodes in the system network must interact with the system and with local and central data base files under conditions where timeliness is of critical importance.

The interface technology described in this paper can support the following basic functions:

- Operations Analysis - Assistance to analysts in assessing and evaluating the conduct and results of tactical operations.
- Planning and Decision Making - Providing the means of reviewing the status of enemy and friendly forces in a given theatre of operations.
- On-Line Simulation - Providing the means for selective display of information with manipulative capability to simulate various battle field configurations prior to selection of a course of action and without disturbing the stored data base files.

Data Communications Networks

Data communications networks exist in a variety of forms and disciplines. There is an increased use of networks in both military and non-military environments. Regardless of the application, network response time is of critical importance in some systems. However, the response time is usually measured as the time between actual input of a message and receipt of a system reply. The message composition time is not included as part of the total response time since it is considered an activity external to the network itself. Yet, this activity is often more time-consuming than the actual network transmission times and should be included as a measured component of total network response times.

The interface technology described in this paper can be applied to network operation to support the following basic functions:

- Assist in network control by providing real-time information relating to transient crises or rapidly developing network overload and a rapid means of adjusting network parameters.
- Dynamic control over the display and queueing for display of messages addressed to the control position.

With an interactive capability as described in this paper, an operator can respond to changing network conditions without interfering with activities at the position. For example, an operator can be alerted to situations requiring his immediate attention without interfering with message composition in process.

Data Management/Information Retrieval Systems

These systems exist in a variety of forms, from specific application oriented capabilities to general purpose systems supporting a diverse group of users. The commonality among most systems is in the basic functions provided; namely, data base generation, update and maintenance, and information retrieval and output. Procedural or task oriented command languages are used, primarily through an Input/Output Typewriter, as

the interface methodology between the user and the system. This device is usually used for both message entry and display of control information necessary to define the functions to be performed.

The interface technology described in this paper can support the basic functions of a Data Management System:

- File Generation - The interactive display together with the touch entry device and menus containing lists of features supported by the system can be used to specify:

- File structure, e.g., serial storage, parallel storage, indexed sequential storage
- Data field definition
- Coding convention
- Access levels
- Maximum size of the file

The technique used to access and define a file can be developed in an interactive touch entry/keyboard environment. In particular, a dictionary identifying all the features of a file as well as trees or hierarchical relationships can be constructed prior to generation of the file.

- File Maintenance - The interactive environment can be used to control the updating of a file and the expansion of a file to include additional fields. A dictionary displayed at touch points plus generated menus can be useful in defining fields to be updated, and the location and attributes of new fields to be added to a file or old fields to be deleted.

- Data Output - The message composition features of the interface technology facilitate the retrieval function. Dictionary terms displayed at touch points plus menus of message and computational processing identifiers can be used to request information.

CONCLUSION

This paper has presented an overall concept for improving the man-machine interface for data acquisition, display and control. The basic technology of this concept exists today and can be applied to a number of systems in which the dialogue between the user and the computer is essential.

Implementation of these concepts has the potential for achieving certain benefits summarized as follows:

- Improvement in total response time.
- Flexibility to easily modify message entry and display functions without disturbing the basic structure of the system.
- Decreased incidence of input errors corrupting a data base or prolonging total response time.
- Facilitating the operation of a position by tailoring the functional capabilities to meet the needs of that position.
- Simplified training cycles due to the self-instructional nature of the interface design in prompting the user in system utilization.

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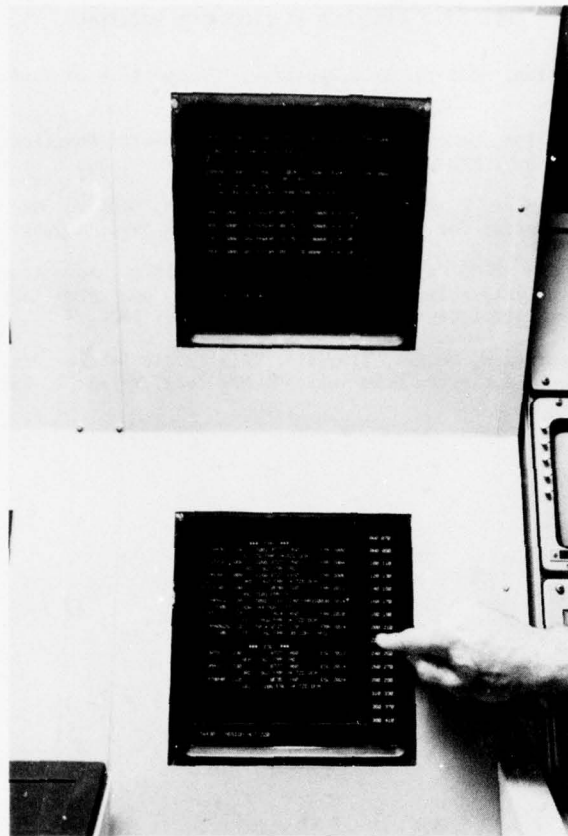


Fig.1 Example direct touch display configuration

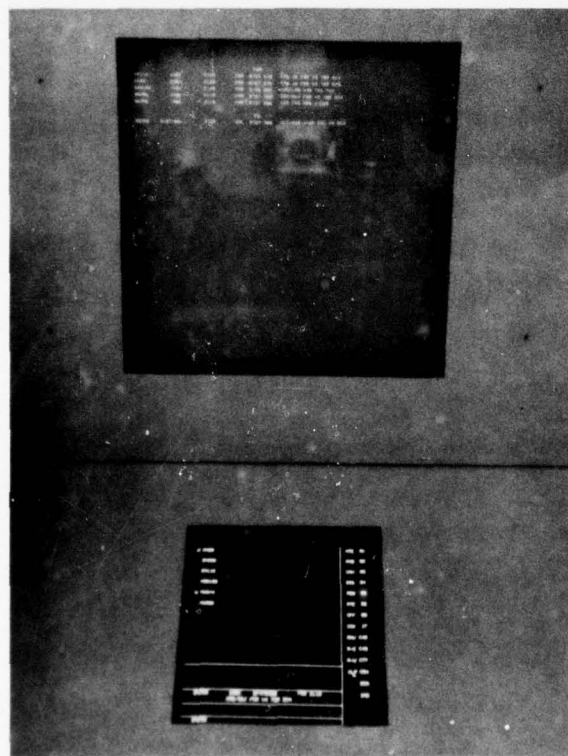


Fig.2 Example indirect touch display configuration

H 0000		NTE 01
BN296		AMD 02
EA116		CAN 03
N56190		DIS 04
H 14044		RDS 05
N4396		RTE 06
		OFF 08
		COX 17
		RMU C42
		R-E C43
		R-W C77
		CLR C94
		DCA
		IAD

BN296	230C	87470300	FRR 2119
	ORD/SGJ	FRR U4 72D DCA	

BN296	
-------	--

Fig.3 Example input sequence – flight data accessed

H 0000		P/P
BN296		ALDIE
EA116		TEI
N56190		FRR
H 14044		ESL
N4396		AML

BN296	230C	87470300	F 2119
	ORD/SGJ	FRR U4 72D DCA	

BN296	HOLD
-------	------

Fig.4 Example input sequence – HOLD action initiated

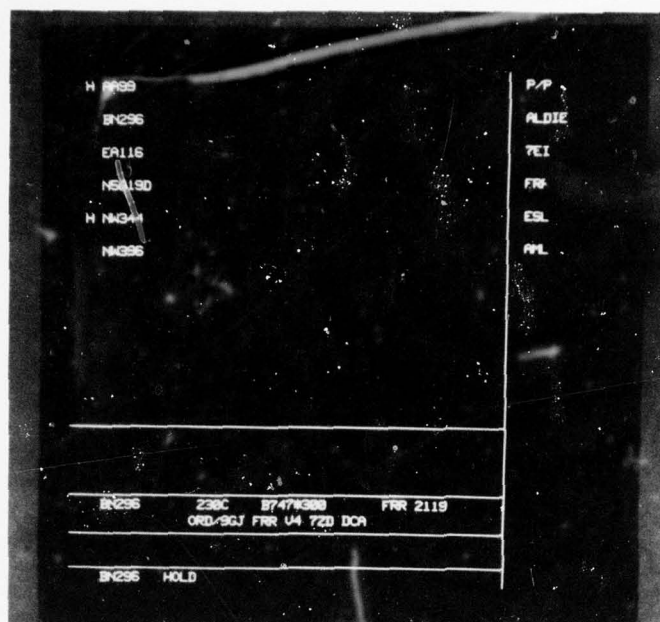


Fig.5 Example input sequence - HOLD fix selected

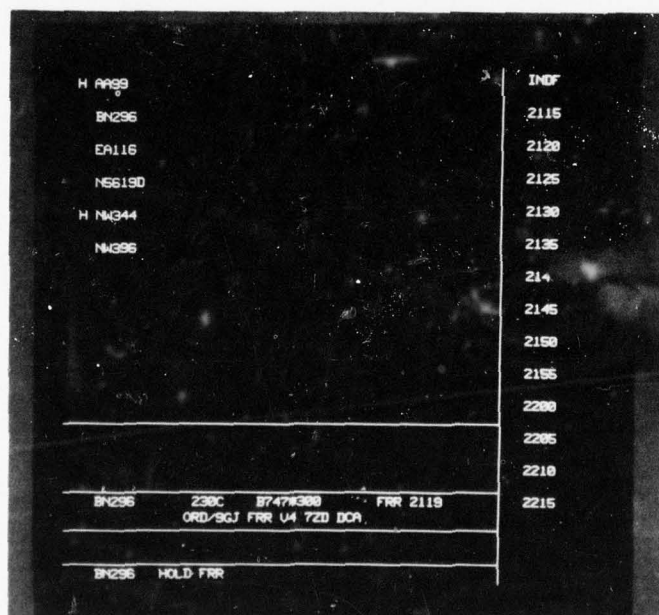


Fig.6 Example input sequence - time selected

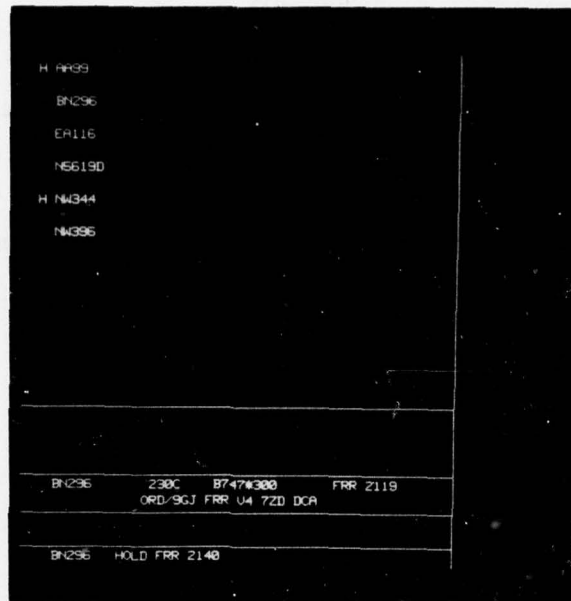


Fig.7 Example input sequence – completed HOLD action

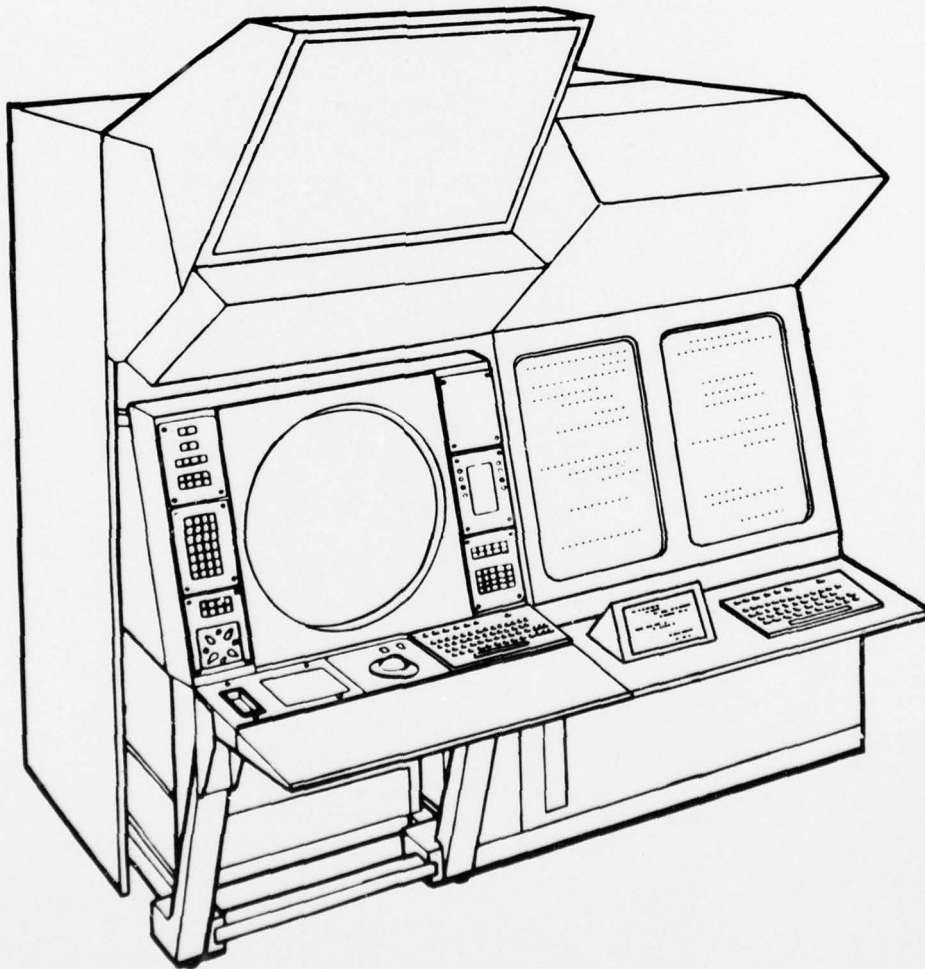


Fig.8 Potential ETABS sector configuration

DISCUSSION

P.E.Boutin

Could you characterise the amount of computer power and memory capacity provided at a given operator station?

Author's Reply

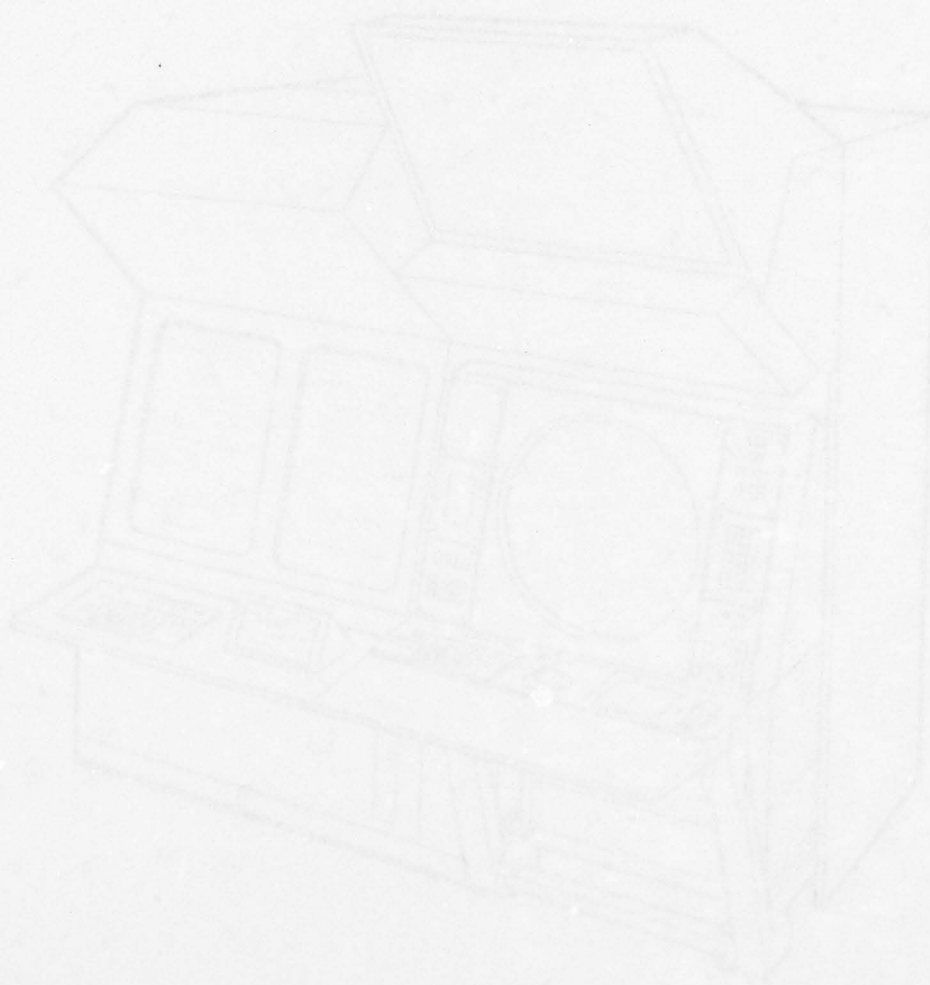
Given maximum loads and specified response times, computer utilization is no greater than 70% on the average. Memory cycle speed is in the 750-800 nanosecond range. Memory capacity is about 96 KB which includes refresh memory for the display devices. Memory utilization is no greater than 80% (allowing room for expansion).

R.C.Makin

Can the operator change the menu?

Author's Reply

Yes.



INTEGRATING SENSORY INFORMATION IN A
MULTISENSOR-SYSTEM FOR BATTLEFIELD SURVEILLANCE

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SUMMARY

This paper describes a part of the "Multisensorstudie" which is performed by Siemens Co. under contract of the German DoD. This study prepares the development of an all-weather reconnaissance system for tactical ground to ground missions. At present, passive electrooptical sensors (TV, LLLTV, FLIR), active microwave Sensors (tracking radar RATAC, 3-D-radar), and a passive microwave radiometer are combined to form a multisensor system. Within this project our institute (IITB) had to solve two problems:

1. The display of information of the 3-D-radar.
This is done by showing a horizontal and a vertical slice of the spatial scene to the observer who can select the position of the slices as well as the displayed depth range.
2. The integration of sensory information from the different sensors. This task essentially is solved by marking spatially corresponding regions in the different pictures by means of auxiliary lines.

During field measurements the combination of FLIR and RATAC turned out to be very useful. The 3-D-radar could not yet be tested.

1. INTRODUCTION

A modern tactical weapon system is expected to operate even at bad weather and poor sight conditions. This implies the need of an all-weather reconnaissance system. The German DoD has assigned the Siemens Co. to perform a "Multisensorstudie" in order to get a basis for the development of such a reconnaissance system. The system should meet the following requirements: It shall be useful for ground to ground reconnaissance up to a distance of about 6 km. Within this range tactical vehicles and helicopters are to be detected and localized; identification of the targets should be done as far as possible. The system has to be mobile and suited for all-weather operation.

These requirements can only be fulfilled by a reconnaissance system which employs different technical sensors and uses their respective advantages. The combination of passive electrooptical sensors and active microwave sensors seems to be a good concept. The electrooptical sensors have the advantage of delivering pictures with high spatial resolution. This is important for the detection and identification of targets and for the determination of their direction. Disadvantages of the electrooptical sensors are the limited all-weather capabilities and poor information about distances. On the contrary the radar delivers good distance-information and gives satisfying results even under bad weather conditions. Furthermore it allows conclusions about the radial velocity of targets using the Doppler-effect. This is important for the detection of moving objects. Disadvantages of the radar are its poor angular resolution and the fact, that it is an active sensor. Thus the electrooptical sensors and the radar sensors support each other. Therefore, one tries to integrate them into one system. The practical value of such a sensor system will strongly depend on the capability of a human observer to make use of the information from different sensors. It was therefore considered how to display and integrate the sensory information such that a human observer is well supported.

These two tasks - the display and the integration of sensory information - were the subject of the work of the IITB. Our solutions will be described in the following.

2. SENSORS EMPLOYED

At the present state of the project the following sensors are tested for their qualification within the planned multisensor-system.

2.1 Electrooptical sensors (see Fig. 1)

- | | |
|------------------------------|---|
| • TV | angle of aperture ca. $10^\circ \times 7.5^\circ$ |
| • LLLTV | " " " " $10^\circ \times 7.5^\circ$ |
| • FLIR (8 μ - 12 μ) | " " " " $6^\circ \times 4^\circ$ |

These sensors are jointly mounted on a common gun carriage. TV and LLLTV deliver pictorial information directly in CCIR-norm while a standards-conversion must be performed for the FLIR-data. In the present state this is done by means of an intermediate image.

2.2 Battlefield surveillance radar RATAC (see Fig. 2)

The RATAC operates in the x-band and has the capability of tracking moving targets. Its outputs are:

- the coordinates of the target position (distance d and azimuth α - no information about elevation)
- a Doppler-tone

The Doppler-tone contains information about the radial velocity of the target and of the type of the target. It is e. g. possible to discriminate between tracked vehicles, wheeled vehicles, and persons by the characteristic Doppler-tones.

2.3 3-D-Radar (see Fig. 3)

The 3-D-radar operates at 35 GHz. It scans a spatial region which extends 12.8° in azimuth, 3.2° in elevation, and about 576 m in distance. The operator can specify the distance d_0 where the scanned region begins. This region is divided into 128 k picture cells with 64 pixels in azimuth, 16 pixels in elevation, and 128 pixels in distance. The results of the radar-measurements are stored in a 128 k byte RAM. Each byte corresponds to one pixel. Normally 7 bits of a byte contain information about the echo-amplitude and two bits contain information about the direction of motion which can be 'coming', 'going', or 'zero' (the parity-bit is used for pictorial information too). When the radar operates in a MTI-mode, the first 7 bits contain information about radial velocity. From the stored radar-data appropriate images can be generated.

2.4 Microwave-Radiometer

Instead of the 35 GHz 3-D-radar a passive microwave-radiometer can be put onto the pivot mounting of the antenna. The radiometer is still an experimental system and was not yet included in our part of the work. Therefore it will not be described here.

3. DISPLAY OF RADAR DATA

For principal and technical reasons the information from the 3-D-radar is not displayed in form of a stereoscopic picture. Instead, two views of the scanned spatial region are displayed on separate TV-screens. Fig. 4 shows the spatial arrangement of the radar images:

1. Top view:

This picture shows a plane with constant elevation. The observer can select one out of 16 elevations or a picture which has been averaged over all 16 elevations.

The appropriate display is a trapezoidal sector-PPI, but for technical reasons we display a rectangular B-scope. The picture format is 64×128 pixels.

2. Front view:

This picture is referred to as "range slice". Its format is 64×16 radar pixels. We display three consecutive range slices simultaneously in order to take advantage of the whole area of the TV-screen. In this view the observer selects the distance of the range slices and - within certain boundaries - the depth of the slices.

The B-scope and the range-slices cover a whole TV-screen each. Therefore the raster of 64×16 or 64×128 pixels is rather coarse. Due to the relative large pixels it is possible to represent the state of motion of each pixel by slowly flickering directed triangles which have the size of one radar pixel. So the addition of motion-symbols causes no loss of pictorial information. A disadvantage of the coarse raster is the fact, that such block pictures are hard to interpret (Harmon, L.D., 1973). Therefore the rastered images are smoothed by means of a twodimensional linear interpolation. The interpolation is accomplished in realtime by special-purpose-hardware. The symbols and auxiliary lines in the radar image are not effected by the smoothing operation.

Fig. 5 shows the structure of the technical solution. The control panel contains control elements for selecting

- the elevation of the B-scope
- the mean distance d of the range slices and the number of radar range gates which have to be summed up to form a range slice.
- the zero-point and slope of a grey scale which matches the 7 bit of resolution radar data to a 4 bit of resolution video image.

From these settings a microcomputer determines the control parameters for a special purpose hardware which generates the radar images. This concept was chosen in order to get a high data throughput.

4. INTEGRATION OF SENSOR INFORMATION

The planned reconnaissance system shall help a human observer to detect, localize, and identify objects of interest such as tactical vehicles. With the multisensor system the observer has the opportunity of gathering all information available from an object of interest. In order to do so the observer must know where to find the selected object in the different pictures. Our concept of integrating the sensory information is to point out where a specified region of the observation space can be found on the different displays or with the RATAC.

For the implementation of this concept the gun carriage with the electrooptical sensors and the pivot mounting of the 3-D-radar were equipped with angle-encoders so that the microprocessor knows where the sensors are looking at (see Fig. 6). In addition the microprocessor is informed about the different angles of aperture. The observer can select a region at distance d , azimuth α , and elevation δ for closer observation by means of two joy sticks which are mounted on the control panel. From these settings the microcomputer selects the B-scope at elevation δ and the range slices around distance d to be read from the 128 k memory. Furthermore the microcomputer determines the position of several auxiliary lines, which mark the selected region in the TV- and radar-images. These auxiliary-lines are set as follows:

- Range slices: The middle slice is that at the chosen distance d . In this picture the angles α , δ are marked by means of a quadratic frame with the size of one radar pixel.
- B-scope: The displayed B-scope is that one at the selected elevation δ . Here the azimuth α is marked by a vertical line. The distance d is included between two horizontal lines which show the near and the far border of the middle range slice. This is done, because a range slice can be generated by averaging over 1, 2, 4, 8 or 16 consecutive range gates of the 3-D-radar.
- TV, LLLTV, FLIR: Similar to the range slices azimuth α and elevation δ are marked by a quadratic frame. But in contrary to the radar picture the size of this frame is variable. In order to encode information about the distance d too, the size of the quadratic frame is set such as if it were the image of a NATO standard target (2.3 m x 2.3 m) positioned at distance d . This helps the observer in detecting and identifying objects because he can check the proportions of the object with reference to the standard target.

In practice the system is used in the following way: The observer notices an object of interest on one of the displays. Then he marks the object with auxiliary lines by means of the joy sticks. Because of that this object is marked in the remaining pictures too. Furthermore the coordinates of the object are sent to the RATAAC so that the RATAAC-observer can examine this region immediately. On the other hand the RATAAC sends the coordinates d , α , of its target point to the microcomputer. If a target has been detected by the RATAAC, the observer can cause the microcomputer to take the coordinates from the RATAAC instead from his settings on the control panel so that the RATAAC-target is marked on the displays.

5. EXPERIENCES

It is planned to test the properties of the multisensor-system during three field experiments with a duration of four weeks each. The first experimental period took place in July/August 1978 on a military training camp. At this time the development of the 3-D-radar was not completed so that no radar data were available. So we have to restrict ourselves to a report on the combination of the electrooptical sensors and the RATAAC. This combination turned out to be very useful. This was especially proven within experiments which simulated realistic conditions: a tactical vehicle was hidden in a distance of 2 + 3 km from the measurement equipment and then moved on a zigzag course towards the measurement equipment. The observers were only told when the vehicle would start moving. Their task was to detect, localize, and identify the vehicle as fast as possible. Since these experiments were performed at night, only the FLIR and the RATAAC gave good results. The vehicles always were detected and localized short time after they had reached an observable area. Usually the target was first detected by FLIR and a short time after that the RATAAC observer gave the distance of the target and discriminated between tracked vehicles and wheeled vehicles. Yet the final identification of the target was possible only by means of the FLIR at relatively short distances.

References:

Harmon, L.D., Scientific American, Nov. 1973

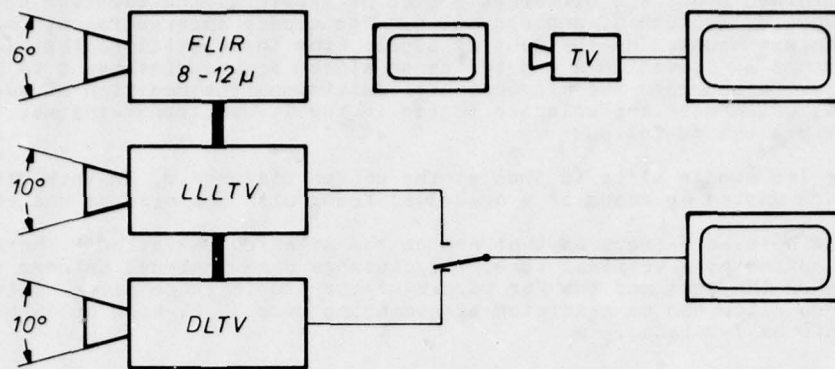


Fig. 1 Electrooptical Sensors (jointly mounted)

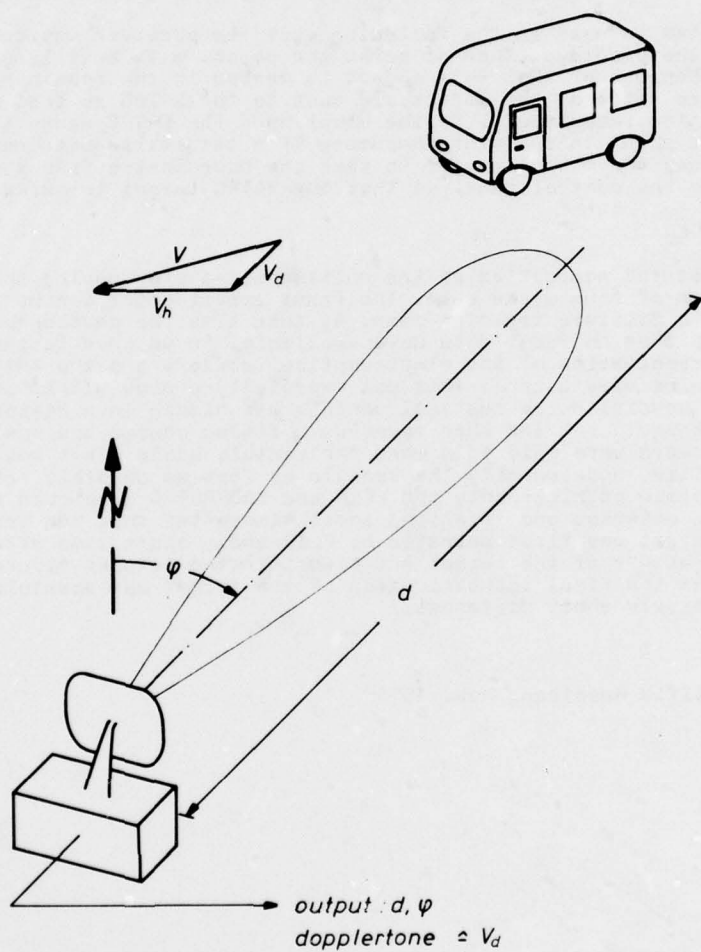


Fig. 2 Battlefield Surveillance Radar "RATAC"

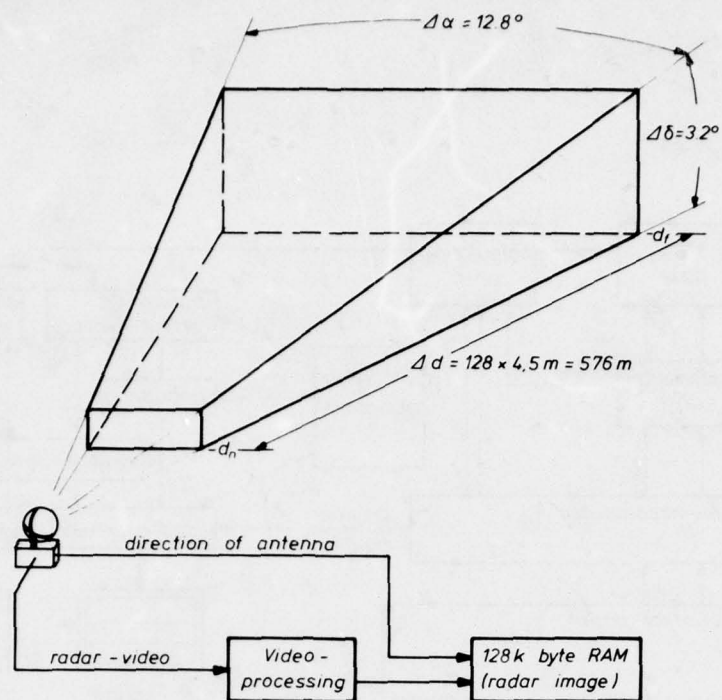


Fig. 3 3-D-Radar

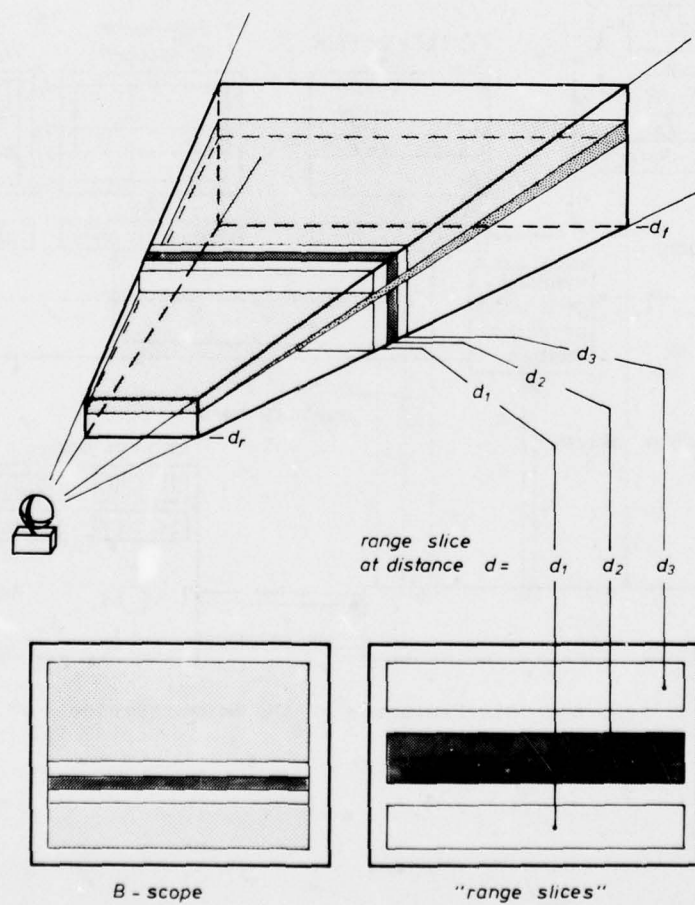


Fig. 4 Geometry of Radar Images

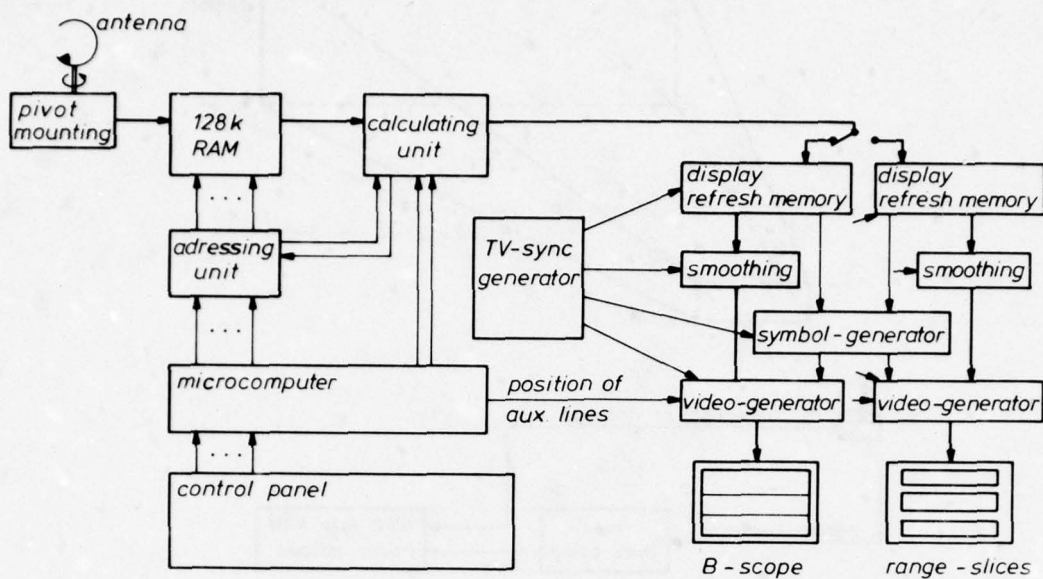


Fig. 5 Generation of Radar Images

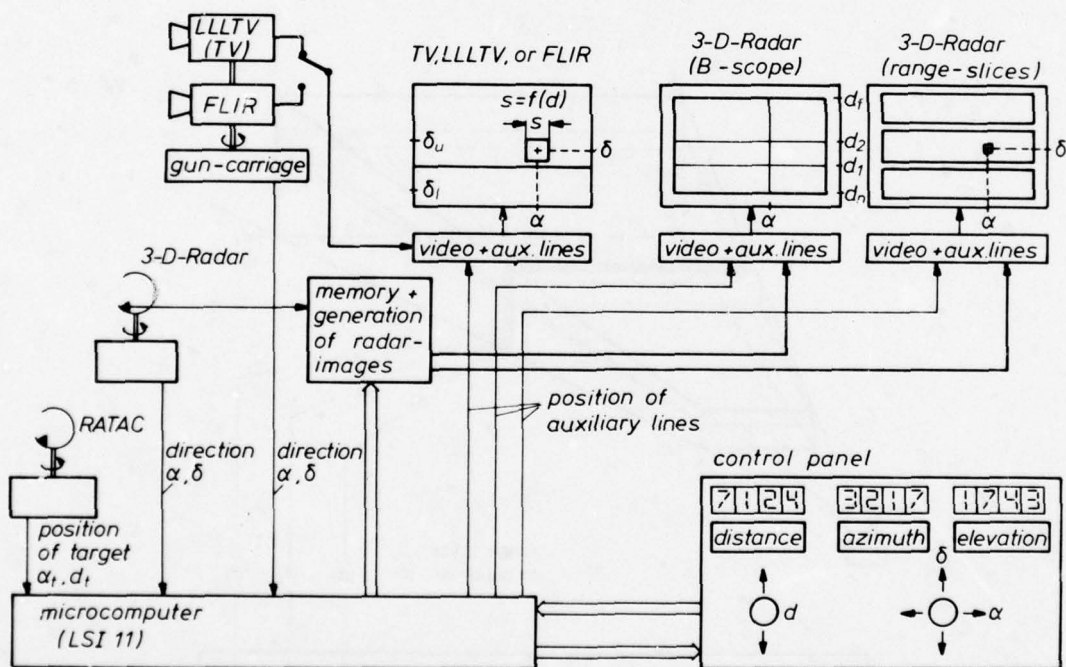


Fig. 6 Block-diagram of the Sensor-system

DISCUSSION

A. Clearwaters

You mentioned a series of experiments with the equipment and indicated you were satisfied with the results. In what way were you satisfied? More specifically, how did your system behave relative to current systems that do the same thing, i.e., a man with a starlight scope?

Authors' Reply

The multisensor system delivers more information to the observer than a current single sensor system does. When in your example a target is detected by means of an electro-optical sensor, the radar can be directed immediately to the target and so the distance and the radial velocity are measured in addition.

TACTICAL RECONNAISSANCE IMAGE EXPLOITATION

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SUMMARY

The advent of improved sensors and data links places the burden of timely tactical reconnaissance image exploitation and reporting on the Ground Processing Facility. The use of multiple sensors such as infrared, electro-optical, and radar will provide a high volume of imagery data via digital data links. That imagery must be effectively digested to produce timely and accurate target reports to the tactical commander.

To practically and economically achieve the capability for exploitation of digital imagery in real time, the performance requirements of the Ground Processing Facility must be carefully established. Examinations must be made of the need for various image handling techniques and the resulting benefit to the image interpreter. Through the selective use of current and planned technologies, an imagery exploitation cycle time of less than three minutes from receipt of imagery through report generation appears to be realistic.

1. INTRODUCTION

The needs of the tactical commander dictate that the exploitation of reconnaissance imagery be accomplished in near real time. The commander faces massive Warsaw Pact forces that are highly mobile and very heavily defended. Timely and accurate target reports are essential in the determination of the targets to strike and the assets to employ. Figure 1 shows a typical reconnaissance/strike cycle where advantage is made of cooperative Air Force and Army reconnaissance and strike information.

To practically and economically achieve the seemingly opposing goals of real time exploitation and handling multiple sensor data rates and formats, the performance requirements for the GPF (Ground Processing Facility) must be carefully established. Trade-offs of the requirements imposed on each system in the reconnaissance and strike cycle are necessary to ensure that major technology, performance, and cost constraints are not imposed on one system while providing only minor relief for another system. The chain of events in the reconnaissance and strike cycle is depicted in Figure 2 where each major system is shown as a link. The design goal is to achieve a balance of system requirements where a weak link does not exist even though many factors strain each link's performance. For example, the use of an airborne image screening device that selects only a portion of the total imagery for transmission to the ground would reduce the volume of data and, hence, the bandwidth requirement of the data link. The corresponding reduction of imagery flowing into the GPF would then allow the image interpreter to concentrate on the more meaningful images and thus reduce the workload. However, today's technology has not yet produced a totally effective airborne image screener. One alternative is to incorporate the image screening device into the GPF where the restrictions of size, weight, power, etc., are somewhat less stringent. In this case, the interpreter retains the benefits of a reduced volume of imagery, but the data link bandwidth has not been lessened.

Similar thought must be given to all design objectives for the GPF such as increased timeliness and accuracy of reports, reduction in image interpreters' training, and allowing for an orderly transition from existing systems to the use of future technologies. Only by consideration of all performance parameters along with applicable technical developments will the system performance requirements for a tactical ground image processing facility be successfully established.

2. TACTICAL RECONNAISSANCE MISSIONS

The tactical reconnaissance mission is the key factor in establishing the performance required of the Ground Processing Facility and other sensor systems. The density and mobility of Warsaw Pact forces in the Central European theater provide ample opportunity for obtaining reconnaissance imagery that is saturated with targets. A basic mission would typically call for low and fast penetration beyond the FEBA to obtain high resolution imagery on potential targets. By taking advantage of multi-sensor cueing, the overall volume of imagery will be reduced and the imagery that is received will contain primarily targets of interest. Therefore, the target detection, classification, and reporting processes can be accomplished easier and faster.

3. IMAGE INTERPRETATION CONCEPTS

The next generation tactical reconnaissance image interpretation facility will be an all-digital operation utilizing soft copy displays for both imagery and text. The versatility and speed of digital image processing allows the requirements for the Ground Processing Facility to be specified in a manner that is practical and cost effective. Top-level functions of the GPF are shown in Figure 3. As is normal in initial system definitions, the performance requirements are driven by both the system inputs, in this case the imagery and associated data, and the system outputs, or reports for the tactical commander.

3.1 Ground Processing Facility Inputs

The reconnaissance mission requirements dictate that the GPF must be capable of handling high volume multi-sensor digital imagery. Data rates in the order of 50 megabits per second and above are anticipated. In addition, imagery resolution of better than 4000 pixels (picture elements) per line with a six-to-eight bit gray level per pixel should be accommodated and must be effectively utilized in the image interpretation process.

A second type of input to the GPF will be external all-source data base information used to establish the initial target area baseline and to provide intelligence updates that are in addition and complementary to the imagery inputs.

3.2 Ground Processing Facility Outputs

The ability to generate timely and accurate target reports is the GPF's reason for existence. The reports will vary, depending on the user, in size and information content and also in the time required to produce them. Small reports such as a HOTPHOTOREP will nominally contain approximately a hundred characters, but must be produced in a few minutes from receipt of the raw imagery. Higher command levels may only require daily reports, but these types of reports will be more comprehensive.

A report will normally contain a textual summary of the exploited imagery. However, the GPF can easily provide a port for transmission of an exploited and annotated digital image to accompany the text or for real time display at a remote location.

The GPF will also provide outputs to remote data bases to periodically update the target situation and enhance the real time knowledge of the battlefield at higher command levels.

3.3 Ground Processing Facility Functions

The GPF must perform a variety of functions in order to accept multi-sensor digital imagery and produce near real time target reports in the tactical environment. A functional block diagram for such a system is shown in Figure 4. A brief explanation of each of the major functions will be presented.

The interface buffer accepts incoming digital imagery and associated data such as time and geographical position. The data is buffered and formatted for subsequent use. A critical consideration is that the imagery buffer be specified in a modular fashion to accommodate future sensor systems without a large impact on the GPF.

Image storage is basically the function of preserving the incoming and exploited imagery for historic purposes. As new imagery is received, it will be stored for later reference. As images are interpreted, they, too, may be stored for later reference by the interpreter or for automatic processing such as change detection.

In order to accommodate the incoming volume of imagery, it is necessary to have automated techniques that relieve the interpreter of a portion of the exploitation burden. A great deal of relief will be provided by the feature extractor. This device performs automatic image screening in real time. The level of screening is selectable by the image interpreter and would range from relatively simple tasks such as detection of man made objects to more complex tasks such as detection, classification, and identification of specific pre-selected targets. An example of the latter type of target would be not merely a tank, but also the class and model of the tank. Other functions that may be performed by the feature extractor are image quality assessment where image quality below a minimum standard would cause automatic storage without interpreter viewing, optimized target presentation where a target is automatically located and centered on the interpreter's display at some desired ground resolution, and automatic change detection where new imagery is automatically measured and statistically compared to historic imagery contained in the local data base.

A promising approach to automatic feature extraction involves edge processing of an image and the measures and statistics derived from the resulting edge map. (ROBINSON, G. S., 1976) A number of edge operators have been developed (e.g., Sobel, Kirsch, Compass Gradient Masks) and some have been effectively implemented in real time hardware. (ROBINSON, G.S. AND REIS, J.J., 1977) The measures taken on an image would include parameters such as edge length, edge directions, edge straightness/curvature, and length-width ratios. By comparing these measures against predetermined measures for various features or targets, it may be possible to automatically classify objects in an image.

The sub-picture extractor is another key element that will relieve the interpreter's burden. By working in conjunction with the feature extractor, the sub-picture extractor will condense the incoming imagery for search and detection operations by the interpreter at full field-of-view and reduced resolution. The sub-picture extractor will also automatically present an image to the interpreter that is full resolution and reduced field-of-view with the target centered on the display. The interpreter may then concentrate on the exploitation task rather than spend time scanning imagery containing no targets of interest.

The actual image that is presented to the interpreter is contained in the refresh memory. The image is in digital form and the size of the image display dictates the size of the refresh memory. Functionally, the refresh memory is constantly updating, or refreshing, the image on the interpreter's soft copy image display.

Real time image enhancement will increase the productivity of the interpreter. Enhanced images allow the human to more easily and quickly recognize information that was contained, but hidden, in the raw imagery. Many image enhancement algorithms have been developed. Some of these would be gray scale stretching, digital filtering for edge sharpening, geometric correction to compensate for sensor-induced distortions, and magnification of the imagery. One of the most widely used techniques to date and one that is also easily implementable in a real time system is gray scale stretch or, in other terms, the alteration of the contrast of the imagery.

Another useful tool in the image exploitation process is alphanumeric and graphics as overlays on the image being interpreted. Symbols such as circles, triangles, coordinate grids, north arrows, etc., may be shown on the image display either automatically by the feature extractor or as inserted by the interpreter. These symbols would be used to highlight and explain features and targets of interest.

The digital mixer combines the original and enhanced image with the selected alphanumeric and graphics. The product is a fully enhanced and annotated digital image that is available in real time for interpreter viewing, storage, hard copy generation, and transmission to a remote location for observation by other personnel.

The system processor performs the overall data management functions. It provides the interfaces with remote all-source data bases and with the appropriate C³ systems. It also maintains the local data base within the GPF where recent target data are contained. Tasks such as data routing and timing control, automated report formatting and generation, data base maintenance, and display and terminal servicing will be accomplished on a routine basis.

The most visible element in the GPF is the image display and operator console. It is here that the interpreter performs the image exploitation and reporting tasks. Because of time constraints, the interpreter must be able to view the imagery and supportive text from one operating position. The imagery is presented on a large field-of-view soft copy display. The spacing between pixels on the imagery display is such that each pixel is resolvable by the human eye to permit the interpreter to utilize the maximum amount of information contained in the image when viewed at full resolution. The related textual information is presented to the interpreter on one or two adjacent soft copy displays. The text contains image related data such as previous reports or target information from SIGINT or HUMINT sources. Also presented on the text displays would be the report format in a form that would allow the interpreter to merely "fill in the blanks" with the necessary information. The processor would then automatically generate and distribute the report in the correct format. Other aids available to the interpreter at the console are a full alphanumeric keyboard, a light pen to use as an "electronic grease pencil" for image annotations, a joystick for image manipulation and control, and the necessary system mode controls.

4. RECONNAISSANCE INFORMATION FLOW

The concepts for the Ground Processing Facility described above lead to a system that is very responsive to the real time image exploitation requirements. Just how responsive the GPF will be in actual battle-field conditions will obviously depend in part on the performance of the sensor systems and the reporting constraints. However, the GPF will not be the weak link in the reconnaissance chain if the requirements are properly identified and met.

As a measure of performance, a typical sequence of events in the exploitation process will be postulated in an attempt to quantify the performance. Assume a relatively simple single sensor input where digital imagery is being continuously received at a rate of sixty megabits per second. The image is 5000 pixels per line (image width) and received at 2000 lines per second with 6 bits per pixel gray level (64 gray levels).

Figure 5 depicts the information flow through the GPF showing the major functions and their associated times. Imagery is received, buffered, and stored. A target related image is then automatically selected and optimized for display through the feature extractor and sub-picture extractor, enhanced for optimum image contrast, overlaid with geographic coordinates and target symbols indicating the type, quantity and location of targets in the image, and displayed on the image display in approximately two seconds. Meanwhile, the system processor has queried the data base for other reconnaissance reports and would, for example, overlay a suspected SAM installation in the image with an ellipse graphic indicating the geographical position of an ELINT detection by another sensor system. The standard report format will also have been posted on the text displays.

The image exploitation and reporting functions that follow obviously consume the vast majority of the time from receipt of an image until the target report is generated for dissemination to the appropriate decision makers. However, by establishing the performance requirements for the GPF with consideration that the goal is to aid the interpreter in completing the image exploitation process, a completed report produced in less than three minutes may be possible.

5. OPERATIONAL CONSIDERATIONS

Operational usability of the GPF is dependent on many factors. The technology to implement the required functions is now available or will be within the near future. But the reconnaissance systems in use today in NATO cannot be ignored. There must be an orderly transition utilizing those assets that are currently available. Emphasis must also be placed on a system configuration that is physically deployable in a tactical environment. The demands of size, weight, power, electromagnetic compatibility, transportability, etc., must be met. Finally, even though many image processing functions will be automated in the future, the GPF requirements must evolve around the capabilities and limitations of the human image interpreter.

6. CONCLUSIONS

A near real time reconnaissance capability is required for digital imagery exploitation and report dissemination in the tactical environment. The imagery will be supplied from advanced IR, radar, and electro-optical sensors in near real time. A Ground Processing Facility that accepts the sensor data and provides the necessary functions for a human interpreter to exploit the imagery and generate target reports almost in real time is achievable. Some basic functional elements that would aid the image interpreter are a feature extractor to screen the incoming imagery and display only annotated target related imagery and an automated report generation and dissemination technique. The critical factor in defining the performance requirements for elements of the Ground Processing Facility is that each element must improve the speed and accuracy of the total exploitation process. The effects of all elements on the performance of the facility must be integrated if the net result is to be a set of viable and realistic performance requirements.

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ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT--ETC F/G 17/2
TECHNIQUES FOR DATA HANDLING IN TACTICAL SYSTEMS. II.(U)
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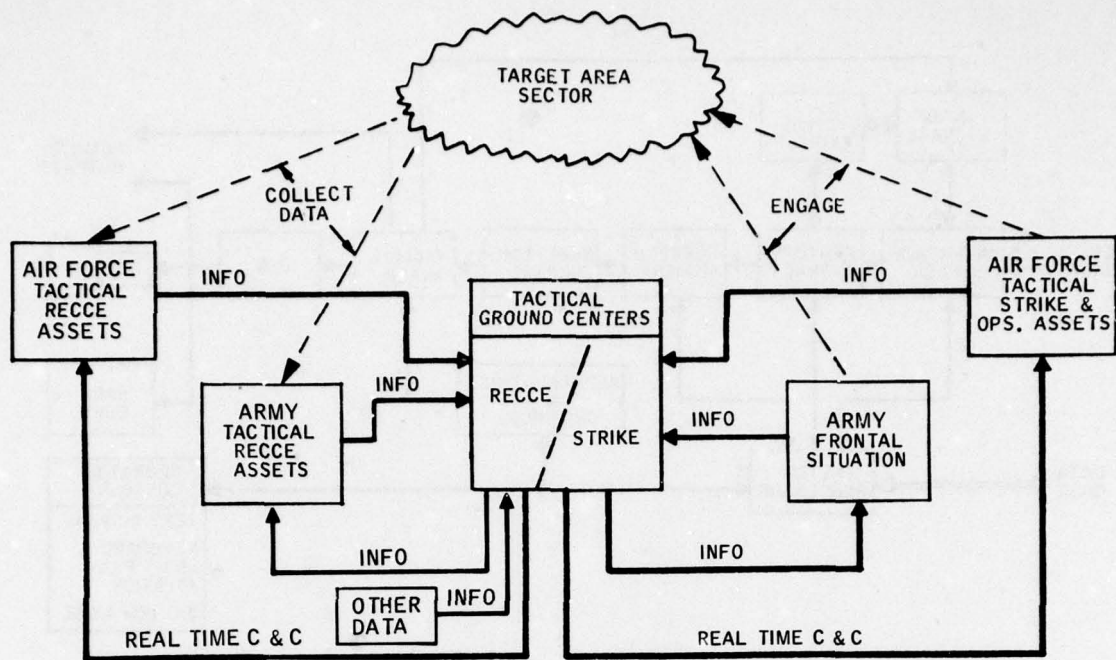


Fig.1 Tactical concepts

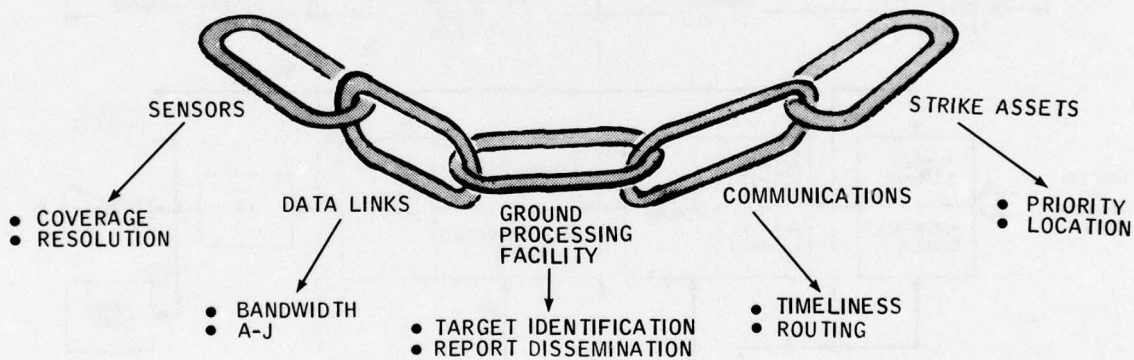


Fig.2 Tactical links environment

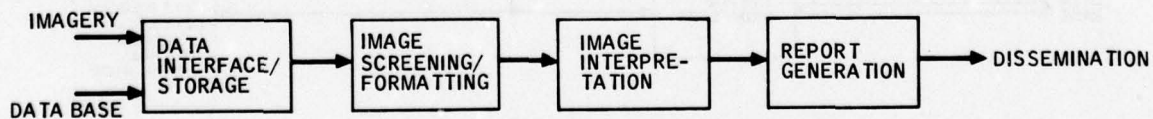


Fig.3 Image exploitation functions

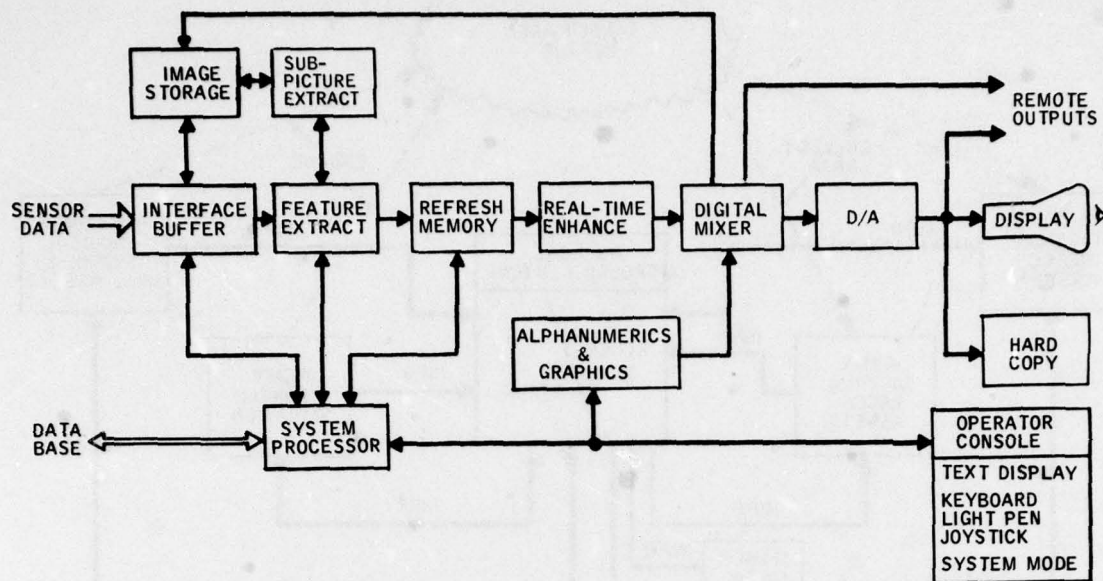


Fig. 4 Ground processing facility block diagram

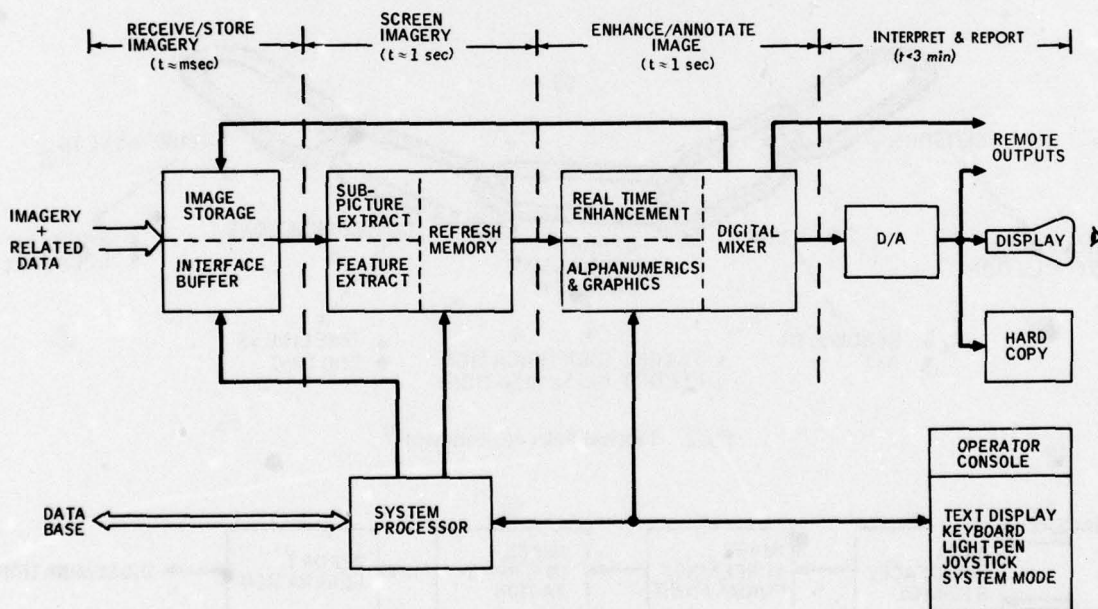


Fig. 5 Ground processing facility information flow diagram

DISCUSSION

D. Bosman

The image bit rate is, as you said, 60 Mbit/sec for your example of system performance. Is this bit rate the result of a compromise or design constraint?

Author's Reply

No. The overall digital data input rate of 60 Mbit/sec is not a compromise or the result of any GPF constraint. The GPF hardware and software can accommodate a much much higher input bit rate. Rather, the 60 Mbit/sec data input rate was chosen merely as an example to represent an input baseline against which the GPF functions and their elapsed times could be measured.

The Role of Advanced Technology in TDMA Systems*

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1. Summary

Recent advances in design technology have proven critical in making Time Division Multiple Access (TDMA) systems feasible for tactical applications. The challenge in these applications has increased as a severe electronic warfare (EW) environment has forced the introduction of highly complex transmitter and receiver functions to realize secure anti-jam signaling. In addition to the complex processing attendant to the integration of communications, navigation, and identification, the anti-jam signaling must be implemented within stringent size, weight, and power constraints.

This paper deals with the technology in two TDMA systems as well as Hughes' projections of impacts of technology trends on such systems. The signal processing techniques discussed include direct sequence pseudonoise modulation, frequency hopping, interleaved forward error correction coding, and residual error detection coding. Circuit applications include (1) programmable matched filters for burst message preamble reception, (2) small sized, precise, agile, rapidly stabilizing, digitally controlled frequency synthesizers, (3) digital symbol demodulators, (4) surface acoustic wave (SAW) devices, and (5) automated network management.

2. The Tactical TDMA System

In certain civilian contexts the term TDMA has come to be identified with "packet switching," or the relaying of burst messages in a distributed multiple user communications system. The tactical TDMA system performs the same communications relay function for widely dispersed users who may be in constant motion. It also provides them the navigation (position location) and identification functions. In the most advanced TDMA systems these are accomplished with a single piece of equipment, using a single integrated waveform.

The communications links, usually UHF or microwave, are exposed to a potent electronic warfare (EW) environment containing high powered brute force jammers, spoof jammers, electronic signal interceptors, and direction finders. The TDMA transmissions must be made as immune as possible from all these EW measures. Now the simple strategy of increasing friendly transmitter power is clearly inappropriate against spoof jammers, interceptors, and direction finders. Against modern brute force jammers (who may enjoy the advantage of short range to their victims) the friendly transmitter power is also inadequate unless combined with spread spectrum signaling. In some systems the friendly antennas are made highly directional to provide anti-jam protection, but in TDMA the functions of communications relaying, navigation/position location, and identification require that each user maintain alertness to all other user transmissions. The distribution of users over a wide geographic area and the need to maneuver will deny the possibility of directional antennas. The remaining means available to gain immunity from EW is the design of a jam resistant, intercept-resistant spread spectrum signal. Such signals are almost universally found in tactical TDMA.

The spread spectrum TDMA signals used in Hughes systems combine the techniques of direct sequence pseudonoise (PN) spreading and frequency hopping. These signals offer the following features:

- (1) Only one user radiates at a time, eliminating the possibility of a "near/far" problem. In other words, the reception of distant transmissions can never be corrupted by strong friendly transmissions from a nearby unintentionally competing transmitter. The near/far problem can occur in other types of systems, such as frequency division multiple access (FDMA) systems with imperfect adjacent channel filtering and imperfect spectrum shaping. The same problem always threatens a "code division multiplex" system if the ratio of the distant transmitter's range to the competing friendly transmitter's range is great enough. Only TDMA is immune from near/far problems.
- (2) All users occupy full system bandwidth for maximum anti-jam processing gain and low probability of intercept. In both of the Hughes TDMA systems to be discussed the combination of direct sequence pseudonoise (PN) modulation and frequency hopping does cause the user signal to occupy the full system bandwidth.
- (3) The high rate PN spreading facilitates time-of-arrival measurements. In both of the TDMA systems to be discussed the PN chip rate (keying rate) is 5 megachip. The propagation distance covered by one chip (minimal signal element) is 200 feet, and under optimum conditions the transmitter-receiver range can be resolved to support most tactical positioning applications.

The Hughes systems to be discussed are called PLRS and JTIDS. The Position Location Reporting System (PLRS) enables Army and Marine Division Commanders to monitor the positions of units under their own command in real time, and enables these units to exchange a limited amount of other critical data. The Joint Tactical Information Distribution System (JTIDS) is an integrated communications, navigation, and identification system to serve military users possibly dispersed over hundreds of miles. Both PLRS and JTIDS use secure anti-jam communications techniques including direct sequence pseudonoise modulation, frequency hopping, interleaved forward error correction coding, and residual error detection coding.

2.1 The PLRS System

PLRS is a portable position location and navigation system using TDMA technology to provide real-time position tracks on hundreds of ground and air user units within an Army Division. To the field user, PLRS is a small box with an antenna and an input/output device. It lets both him and his commander know where he is, and provides him

*These systems are being developed under U.S. Army contract DAAB07-76-C-1750 and U.S. Air Force contract F19628-75-C-0205.

access to the common user data base at the master unit. To the commander, PLRS is an electronic map which represents the exact location of all of the PLRS equipped units within his area. Users' locations are known to within a few meters, and each can send and receive information through relays when no direct line-of-sight path exists to the master unit.

The system is made up of two different types of units. The Master Unit (MU) controls a network of a few hundred user units and provides a central display of their locations. The user unit (UU) is designed for manpack operation. However, functionally and physically identical units are employed in aircraft, helicopters, or ground vehicles using appropriate installation kits. Each unit consists of all of the equipment necessary to enable its location by the master unit and to send and receive digital messages. Both the MU and UU's are designed for operation in hostile electromagnetic environments. Figure 1 shows the zones of high density of manpack user units and the zone of deployment for master units within an Army area.

Each user transmits a self-identifying signal burst on a precision time-ordered schedule, measures time-of-arrival (TOA) of the other UU transmissions, and automatically relays these measurements in time slots in which the MU has "preprogrammed" it to do so. The MU computes and continuously updates the position of each UU. Figure 2 illustrates this process.

Position locations of every PLRS-equipped unit may be:

- Remoted and displayed at Command and Centers for decision making.
- Sent to PLRS UU's, either automatically or on request.
- Displayed in the MU for network management and technical control.

Position location and navigation information exchange between the MU and any specified UU is performed by means of PLRS-formatted digital messages. Additionally, a limited free-text message transfer capability is provided. All PLRS messages transmitted are cryptographically secure and identical in their spectral signature regardless of their content.

Because it utilizes composite frequency-hop direct sequence spread spectrum techniques, PLRS possesses inherently high jam resistance and can operate in hostile electromagnetic environments.

2.2 The JTIDS System

JTIDS is a time division multiple access communications system designed to operate in the 960-1215 MHz TACAN band. It provides the military services with a secure anti-jam data link to operate in the tactical environment of the 1980's, spanning a geographic area of up to 500 miles.

The time division aspect of system architecture allows multiple users to participate in the communications network. The parameters of the system waveform (to be discussed later) are strongly influenced by data communications transfer rate requirements. This contrasts with PLRS, where the waveform is designed primarily for position location.

Each terminal in the JTIDS network is assigned a number of time slots in which it can broadcast or relay messages. In the distribution concept shown in Figure 3, all terminals in the net can listen to all time slots in which they are not transmitting. Code division multiplexing can be used to provide multiple communication networks which have overlapping coverage patterns. A terminal can switch between multiple networks on a time slot by time slot basis. The terminals have the capability of transmitting and relaying both formatted messages and free text messages (i.e., for digital voice and TTY). Position messages which define the position and position quality of the user are transmitted regularly to support the multilateration function which will be included in the production terminals.

2.3 The Waveform Architecture of PLRS and JTIDS

The common waveform architecture in PLRS and JTIDS reflects the similarities in the general requirements on the two systems, and the differences in waveform parameters reflect both the differences in the detailed requirements and the contrasts in the environments of the systems. The waveform parameters also carry significant implications for hardware implementation.

The cyclic transmissions are organized into a hierarchy of epochs, frames (as in PLRS or, alternatively, cycles in JTIDS) and time slots. This scheme is illustrated in Figure 4.

2.3.1 The PLRS Waveform Parameters

The PLRS time division structure simultaneously accommodates both minimum and maximum update users. These range from manpack units requiring update rates approximately once every minute to high performance fixed-wing aircraft with desired updates 30 times per minute. This wide range of update rates can be effectively accommodated within an epoch and frame timing structure which also provides as many time slots as practical to service a 5-community network of over 370 users per community. The PLRS parameters are shown in Figure 5.

The fundamental time division of the system is the time slot. Within a single PLRS community, only one normal data message transmission is allowed in a time slot. The normal mode is one transmission per time slot with multiple receptions of that transmission. The time slot length is about 2 ms. The burst transmission accounts for 800 μ s, and 630 μ s is allocated to RF propagation delay. The balance of the time is required for processing overhead such as message encoding, validation, and guard time.

The PLRS frame contains 128 time slots and is 1/4 second long. The significance of the frame is that it represents the highest rate at which a unit can be programmed to transmit a user measurement report (UMR). That is, a unit can be programmed to perform a set of functions including a set of up to four relay actions, a set of up to four TOA measurements, and a report transmission as often as once every frame (every 250 ms).

The epoch is the largest time division which is significant to the PLRS network. The longest interval for which a unit can be programmed to repetitively transmit its own UMR is once every 256 frames, which equals once per epoch. The epoch is 64 seconds long. The net can be said to be periodic with respect to the epoch. The programmed cyclic transmissions and receptions do not change from epoch to epoch unless: 1) the MU alters a unit's program for net reconfiguration purposes, 2) a unit is brought into the net, or 3) a unit loses radio contact with the net.

Each user unit's clock keeps track of time in time slots and frames. By so doing, each unit can be programmed to perform specific actions (transmit, receive, measure TOA, etc.) in each epoch.

2.3.2 The JTIDS Waveform Parameters

Figure 6 shows how time in JTIDS is divided into time slots, cycles, and epochs. Time slots for transmission are generally made on the basis of 2^N time slots per 12.8-minute epoch, where N can vary from 0 to 15 (i.e., from 1 to 32,768 time slots per set per epoch). The repetition rate of time slots is compatible with the 75×2^N bits/second standard transmission rates for TTY instruments. The 7.8125-millisecond time slot is partitioned, as in PLRS, between the burst transmission and the propagation/guard times.

Further details of the JTIDS waveform are worth considering for their hardware implications. Figure 7 shows that the 3354- μ s transmission burst comprises 129 symbols, each of duration 26 μ s. Each symbol consists of 1 or 2 pulses, each of duration 6.4 μ s. The transmitter executes a frequency hop for every pulse, or one hop per 13 μ s. Note the contrast with PLRS, which dwells for 800 μ s on the same frequency. Also, the JTIDS propagation/guard time is 4.4585 ms as compared with 1.2 ms for PLRS. This difference reflects the contrast in typical geographic separations between users, tens of kilometers in PLRS versus hundreds of miles in JTIDS.

3. Hardware Implications of Tactical TDMA Waveform

The class of tactical TDMA waveforms under consideration requires certain operations in hardware which are not commonly found in other types of systems. These are now discussed together with Hughes' circuit realizations.

3.1 Preamble Acquisition

Many users, constantly in motion, report infrequently in a typical TDMA system. One consequence is that the users are not presynchronized in time or phase to the arriving signal modulation. The waveform organization into regular transmission time slots can be maintained by relatively unstable (~ 1 part in 10^{-6}) individual user clocks. Thus, the necessity for the preamble acquisition function in a burst TDMA system arises. The preamble portion of the message burst is used to ascertain if, and precisely when, a burst message was received. In addition, as the PLRS waveform employs coherent data detection, an initial carrier phase estimated accurate to within $\pm 45^\circ$ is also derived in the preamble detection circuitry.

The question of analog vs digital implementation of the preamble correlator is interesting. The analog approach is theoretically superior in additive white gaussian noise (AWGN), although a 2-bit/sample digital approach causes a basic loss in AWGN of only ~ 0.6 dB. The analog devices (e.g., SAW's and CCD) 1) are more difficult to make programmable, 2) cannot achieve as large a time bandwidth (TW) product and 3) are more temperature sensitive. On the other hand, a digital implementation allows for ease of high speed programming, large TW products, and wide operational temperature ranges.

Since preamble acquisition detection is inherently non-coherent, chip samples must be taken from both an in-phase (I) and a quadrature (Q) channel. Hence, with 2-bit sampling, four sample registers and a reference register are required in the correlator chip. The 2-bit samples from each channel are compared (correlated) to a reference pattern, as shown in Figure 8 for the PLRS system. The individual chip comparisons in each channel are coherently summed, with proper weighting to the least and most significant bits. The correlation outputs from each channel are squared and then summed before being compared to the threshold. The threshold is uniquely determined by the established probability of false alarm (PFA).

3.1.1 Preamble Correlator Implementation

The PLRS preamble is transmitted at a rate of 5 megachips per second. The correlator is digital 2-bit/sample and programmable from time slot to time slot. Figure 9 presents size comparisons that show the extent of reductions that have taken place. The engineering development model (EDM) breadboard, occupying the right half of the figure, contains 10 CMOS LSI correlator chips shown as separate circuit components on the board. The entire breadboard has been reduced to a single LSI hybrid, as shown in the upper left. This hybrid is approximately 5 cm long and consumes 220 milliamps at 12 volts when clocked at 5 MHz. In the lower left is the system validation model (SVM) breadboard, an earlier design which performed the same function (although with only 1 bit/sample).

The JTIDS preamble consists of 32 frequency hopped segments, each 32 chips long and transmitted on a different frequency. Since the chip rate is the same in JTIDS and PLRS the JTIDS preamble correlator uses the same CMOS LSI correlator chip as PLRS, except that in JTIDS a different TW product obtains.

Incidentally, the JTIDS 32 stage correlator chip is also used for 32-ary signal detection. The JTIDS signalling format is basically 32-ary noncoherent orthogonal and is referred to as cyclic code shift keying (CCSK) because each of the 32 signals is a cyclic shift of a 32-chip reference pattern. Therefore, matched filter detection of the information content is achieved by using a single digital correlator in which a 32-bit reference pattern is shifted through its 32 possible states. The largest correlation yields the maximum likelihood estimate of the signal transmitted. However, if none of the correlations is sufficiently large an erasure is declared (the symbol will hopefully be determined by the error correction code, see section 3.3).

3.2 Frequency Synthesizer

As mentioned previously, frequency hopped TDMA systems require frequency agility to frustrate both interceptors and jammers. The JTIDS system places stringent demands on the agility of the synthesizer, for in JTIDS the frequency hop takes place every 13 μ s. A description of the JTIDS frequency synthesizer follows.

3.2.1 The JTIDS Frequency Synthesizer

The 32 pulses of the JTIDS preamble (each pulse 6.4 μ s long) are distributed over multiple frequencies. Because, by definition, the receiver does not have advance knowledge of the arrival time of the preamble it must provide multiple simultaneous RF channels for preamble reception. Once synchronization is achieved via the preamble then one frequency hopped RF channel is sufficient. Of course, only one frequency hopped channel is needed for transmission of an entire burst message, including the preamble.

In the Hughes Improved Terminal (HIT) for JTIDS the transmitter/receiver (T/R) is designed to have one transmit channel in the 969-1206 MHz frequency band and multiple receiver channels covering the band. The total T/R hardware consists of a Reference Oscillator, an RF Limiter, an Up-Down Converter module, a Modulator module, an Amplifier Switch module, and four Synthesizer/Detector modules.

Figure 10 is a simplified block diagram of the T/R. The RF signal designated RCVR INPUT enters the T/R through the diode limiter. Here, the signal is power limited to less than 50 mW in order to avoid damaging the low noise front end amplifier in the down-converter. The first mixer translates the Tacan band frequency of 969-1206 MHz to a 369-606 MHz IF. This first IF signal drives the receiver-detector channels. Each of the receiver-detector channels has its own synthesized local oscillator (LO) which translates the first IF signal to a second IF at 315 MHz. This signal passes through a surface acoustic wave (SAW) matched filter and is translated to a base-band frequency of 1.25 MHz by mixing it with a 3rd LO of 313.75 MHz in the I and Q phase detectors. The I and Q signals are sampled and converted to the four digital signals shown in Figure 10 at the output of the comparator, which are then sent to the signal processor. In the data mode, only one detector channel is used, and the remaining programmable synthesizers are time shared (caroused) to provide the LO signal. Thus the required settling time per synthesizer is $4 \times 13 = 52 \mu$ s.

The synthesizer is capable of generating all the first LO frequencies from 684 to 921 MHz in uniform steps. It is designed to change frequency and be stable in less than the required 52 μ s. During the preamble mode, each of the synthesizers is set to a particular frequency for that channel well in advance of the time slot. Each synthesizer frequency is fixed for the duration of the preamble. However, during the data mode of the receiver, the LO frequency must change for every time segment (i.e., pulse) of the received waveform. Thus, four synthesizers are used to support a data channel. Each synthesizer is set-up ahead of the scheduled time usage and is then caroused to the receiver down-converter via a single-pole 4-throw switch in the amplifier switch assembly.

The Synthesizer/Detector assembly consists of two identical receiver channels and two identical LO frequency synthesizers. Both receiver and synthesizer channels are identical. In order to minimize cross talk between channels, each synthesizer is packaged in its own cavity and separated from the cavity which houses the two receiver channels. A photograph of the assembly is shown in Figure 11.

The synthesizer circuit can be divided into four major functional areas. The first is the "frequency word memory circuit" which converts the serial frequency word input into a parallel word output which sets the divide-by-n ratio of the phase lock loop. The second is the "present circuit" which gets its input from the frequency word memory circuit and applies a dc voltage to coarse-tune the voltage controlled oscillator (VCO) close to its desired output frequency. The third is the "phase locked circuit" which generates a dc voltage to fine tune the VCO to the exact frequency of n times the 1.5-MHz input reference frequency. (The frequency word selects the absolute value of n and thus the output frequency. The phase detector and the loop filter are part of the feedback circuit to maintain coherence between the output frequency and the input reference.) The fourth is the VCO which is a thin-film hybrid tunable over the 342 to 461 MHz band. The oscillator frequency is doubled inside the hybrid to generate the 684-921 MHz LO output.

The synthesizer/detector module utilizes state-of-the-art technology in both the circuit design and the packaging. The VCO in the synthesizer is a thin-film design due to the high frequency and broad bandwidth requirements. The thin-film technique is repeatable from unit to unit and hence is suitable for production in large quantities.

3.2.2 The Surface Acoustic Wave (SAW) Oscillator

A unique application of surface acoustic wave (SAW) technology is found in the modulator assembly.

The modulator generates a low frequency reference signal of 1.5 MHz and a 40-MHz clock signal using transistor multipliers and IC dividers. It also generates a phase-locked 1.25-MHz internal reference for its two phase-locked loops. One of the phase-locked loops generates a 313.75-MHz signal for use as the receiver phase detector LO. The feedback and phase detector circuits of the phase-locked loop are a very straightforward design while the SAW VCO is a novel design with a new technology. The SAW device is a time delay element with a narrow frequency band-pass characteristic at a UHF frequency. When the SAW device is connected in series within the feedback path of an oscillator, an oscillation will occur at the frequency of the narrow SAW band-pass. In addition, if a voltage controllable phase shifter is added to the same path, the oscillator frequency can be shifted and hence phase-locked to a harmonic of the 1.25-MHz reference signal. The advantage of using the SAW device at 313.75 MHz is that this technique

eliminates a frequency multiplier which would have to be used with a low frequency voltage-controlled crystal oscillator to generate a LO signal with the required frequency and stability. Figure 12 is a photograph of the SAW device.

3.3 Error Control Coding

Digital messages of the sort being transmitted in TDMA systems require extremely low probability of incorrect message acceptance, PFMA. Typical messages might be 1) command messages that modify operation of units (e.g., time slot assignment), 2) time of day messages for synch, 3) position reports, 4) status reports, 5) time of arrival measurement reports for the position location function. To guard against the acceptance of incorrect messages, the data are first encoded purely for error detection. Before the receiver releases any message, that message is validated by checking the consistency of the received data and parity check bits. This message validation and the user address check maintains a very low PFMA.

In addition, error correcting codes are frequently utilized in TDMA waveforms for enhanced signal to noise and anti-jam (AJ) performance. Both convolutional and block codes have been employed in the past. Both the PLRS and JTIDS waveforms employ message validation coding and interleaved error correction coding.

3.3.1 Error Detection/Correction Hardware

The error control coding for the PLRS waveform is based on an error correction Hamming code and a shortened cyclic code used for message validation. The necessity of minimizing the size, power and weight of the PLRS manpack unit was the principal reason for selection of a simple and not very powerful code. In fact, the SVM phase waveform was uncoded, but interference from friendly radars caused appreciable message loss. Hence, the interleaved coded waveform provides for operation with ~10 high power radars while also providing increased protection from pulse jammers. Each PLRS burst message, Figure 13, consists of information bits and message validation bits which are encoded as code words. The breadboard message validation encoder/decoder and its equivalent CMOS LSI are shown in Figure 14. The LSI circuit consumes only 10 milliwatts at 5.2 volts when clocked at 1.25 MHz. The error encoding/correction and interleaving/deinterleaving function has also been implemented with custom CMOS LSI as shown in Figure 15. This device dissipates less than 5 milliwatts at 5.2 volts. Note that in a TDMA system these devices are not constantly in use, and that the standby power of CMOS devices is virtually negligible. Therefore, the total energy drain (e.g., from batteries) by these devices can be kept very small.

The JTIDS architecture provides for both uncoded and coded transmissions. The error correction coded JTIDS waveform is based on the powerful (31,15) Reed-Solomon code.

Figure 16 shows the format used for transmitting the Reed-Solomon error correction coded message. There are three (31,15) Reed-Solomon code words and a special (16,4) Reed-Solomon Header. The (31,15) words contain 31 five-bit symbols (155 bits) of which 15 are five-bit information symbols (75 bits). This leaves 16 five-bit parity symbols to be used for error correction. Each (31,15) code word can correct up to eight symbol errors, or up to 16 erasures (no decision on which symbol was transmitted) or any combination of errors and erasures in which:

$$2 \times (\text{number of errors}) + (\text{number of erasures}) \leq 16.$$

To insure that pulsed interference does not saturate the error correcting capability of any single Reed-Solomon code word, the symbols are not transmitted in order, but the order is permuted over the 109-symbol message by a fixed permutation pattern. The inverse operation is supplied at the receiver before decoding operations.

In addition to the error correction capability of coded messages, a special error detection code is added to all formatted messages. This code supplies 12 parity bits designed to trap any messages containing errors missed by the Reed-Solomon decoding operation. This code reduces the probability that a formatted message contains undetected errors to a very low PFMA.

The (16,4) Reed-Solomon Header is used in both coded and uncoded messages. In formatted messages it contains information about the message type and the 12-error detection code parity bits. In free text messages, it contains message type data and a 16-bit code identifying the transmitting terminal.

The present implementation of the RS decoder takes 4 cards of ~50 MSI devices each and consumes 22 watts of power at 5 volts. The unit can decode a (31,15) RS code-word in 650 μ s, worst case. An ongoing IR&D effort will reduce the size and power of the decoder to 1/2 card and 5.0 watts. The new design is being implemented with I^2L LSI.

3.4 Accomplishing Spectrum Control in a Frequency Hopped System

Even though the TDMA system bandwidth is intentionally made very wide by spread spectrum signaling there are stringent controls on the radiated spectrum. These controls take the form of specifications on the "instantaneous" power spectral density, the spectrum that is observed while the transmitter is dwelling on one of the available frequencies in the frequency-hopped bandwidth. The instantaneous spectrum is generated by the direct modulation of the PN chip stream on the carrier. In the PLRS and JTIDS systems, as mentioned previously, the modulation is at 5 mega-chips per second. Figure 17 shows the typical JTIDS spectrum centered, in this instance, on an RF carrier at 969 MHz. It is produced by a filtered form of the commonly known Minimum Shift Keying (MSK) modulation method [Amoroso and Kivett, 1977, Amoroso, 1976] and presents greatly reduced spectral sidelobes in conformity with a stringent specification. At Hughes the filtered version of MSK is called CPSM (continuous phase shift modulation). The spectrum shown was measured at the output of the RF power amplifier driven into saturation.

The unique spectrum realization requirement in a frequency hopped TDMA system, a requirement met in PLRS and JTIDS, is to produce an acceptable spectrum without the use of an RF filter following the power amplifier stage. Clearly no fixed RF filter is appropriate since the RF carrier is, by design, frequently changing. Neither is it technologically feasible to "hop" an RF filter to follow the carrier. A further complication enters from the need to have

a prime power efficient RF output stage. High prime power efficiency usually means an amplifier driven to saturation, such as a class C amplifier. In other words the radiated signal should have a constant carrier envelope. The literature is replete with methods for synthesizing and filtering data signals to produce excellent spectra, but by and large these methods lead to non-constant carrier envelopes. MSK modulation is remarkable for its production of a constant envelope signal with relatively small spectral sidelobes. The circuit techniques for realizing MSK have been somewhat cumbersome in the past. Hughes has improved considerably on them for PLRS and JTIDS.

Figure 18 shows an early Hughes circuit used in the Wideband Command and Control Modem (WCCM), to generate CPSM at 60 Megachip. This circuit was about as complex as those reported by other investigators [Mathwich et al., 1974]. One disadvantage of this circuit was the size and cost of its large number of components: four mixers, two narrowband filters, two delay flip flops, circuits for dividing by two and four, an adder and a square wave clock separate from the incoming bit stream. Perhaps a more fundamental difficulty was the need to keep all the components precisely time-aligned to within a fraction of a period of the IF oscillator.

The current Hughes modulator for both PLRS and JTIDS, strikingly simple, is shown in Figure 19. The basic operation of this circuit has been adequately explained [Amoroso and Kivett, 1977]. The $h(t)$ filter, realized as a single SAW device, incorporates additional filtering necessary to reduce spectral sidelobes much below those commonly found in MSK, thus producing CPSM. Figure 20 gives a schematic representation of the SAW device, which is passive and time-invariant. It exploits the design versatility of interdigital transducers to achieve the desired spectral sidelobes. The frequency response of the input transducer is trapezoidal shaped to pass the main lobe of the spectrum virtually undistorted while suppressing sidelobes. The modulation is performed at IF, ultimately leading to the spectrum of Figure 17.

As described previously [Amoroso and Kivett, 1977], an equally simple demodulator circuit recovers the chip stream at the receiver. A SAW matched filter appears there to gain the usual performance advantages in noise. Figure 21 shows a photograph of the complete modulator and receiver matched filter.

Research continues at Hughes to improve the spectrum without sacrificing the circuit simplicity.

3.5 Network Management in the Tactical TDMA System

The PLRS and JTIDS systems use contrasting modes of network management, with corresponding differences in hardware configurations. The JTIDS system is "distributed," i.e., there is no master unit which assumes the function of structuring the network. PLRS is centrally managed, with a large share of the computing for all user units being performed at the master unit. One consequence is that the PLRS user units have been reduced to manpack size, in comparison with the larger units of JTIDS (more detailed size comparison will be given later). A discussion of the PLRS network functions follows.

3.5.1 Network Functions in the PLRS System

PLRS functions in a dispersed, mobile, primarily ground environment. A complex management function has evolved out of the need to maintain continuous reports from hundreds of units while many of the units, being in motion, acquire (and lose) radio line of sight to other units over sometimes irregular terrain. The maintenance of communications link assignments among UUs is a critical management function of the MU, for most UUs depend on the integral relay capability of other UUs to provide a communications path back to the MU. A single PLRS network can consist of several Master Units (MUs), each with a community of a few hundred user units (UUs). All of these units operate in a synchronous time-frequency structure such that no significant mutual interference results. All data is transferred with cryptographic security and privacy under MU control.

Network management within PLRS involves several aspects of system design, network architecture, allocation of time-frequency resource to the MUs, assignment of resource to the UUs, and division of responsibilities between the MUs and UUs. Because of the emphasis on minimum size and cost of the UU and on operation of the UUs by personnel with very little training, the more complex functions are performed at the MU where practical.

PLRS uses the concept of transaction groups, rather than individual time slots, for assignment of resource and functions to the UU. Using this approach a repetitively timed loop of up to 16 time slot assignments can be made with a single command from the MU to a UU.

The UU has several responsibilities relative to network management. The UUs obtain coarse ($\pm 100 \mu\text{sec}$) timing from the MU or other UU over up to four levels of relay. They demand access for network entry or data, and they monitor for commands or data addressed to themselves. Once active network entry has been achieved the UUs routinely report data to the MU consisting of time of arrival and barometric measurements, communicant IDs, access demands, and intercommunity contacts. UUs also perform assigned relay functions including intercommunity data delivery.

The MU has the major responsibility for network management. These responsibilities include message traffic control, reporting and performance monitoring, in addition to the basic function of assigning relay paths and cross-links. Message traffic control consists of reviewing the current message (data and command) distribution requirements in conjunction with the available relay paths and scheduling traffic based on priorities. Reporting consists of reviewing all of the data requests for availability and authorization and then queuing requests and data messages. Reporting also formats data messages both for delivery over the PLRS network and to an interface control function for data exchange with command and control centers. Of course the key function of network management is link assignment. Network management reviews the current network link assignments, link reliabilities and desired reporting rates to build and optimize the network assignments to the UUs.

3.5.1.1 The PLRS Master Unit Processors and Peripherals

The MU processors and peripherals occupy the better part of an S-280 equipment shelter, which also houses the MU operator. The volume is 614 cubic feet.

The processing requirements of the MU dictate that the computation subsystem include an AN/UYK-7 and two AN/UYK-20 processors. The allocation of tasks to these computers is, in general, as follows: The network control task to one AN/UYK-20; tracking, filtering and simulation tasks to the AN/UYK-7; and display control and remote input/output (I/O) handling tasks to the AN/UYK-20 (see Figure 22). These processors were selected because of their applicability to real-time and data handling problems, their advanced design, their existence in the Government inventory, and their basic compatibility.

Both of the selected processor types are highly reliable, ruggedized computers with versatile functional architectures. These units are designed to operate in the hostile ship and shore environments characteristic of the operational environment in which PLRS will be deployed.

The AN/UYK-7 computer is available in either single or multiple processor configuration with capabilities up to 48K words of memory and 16 input/output channels per cabinet. The single-bay configuration, with 48K words of memory and four I/O channel groups, has been selected as appropriate for the time of arrival (TOA) processor. Two of the I/O channels of the AN/UYK-7 will be assigned to the interfacing AN/UYK-20 processors.

The AN/UYK-20 computer is a highly efficient processor well suited for real-time communications and display controlling applications of the type found in the MU.

Network Control Processor - The AN/UYK-20 I/O channel set is configured with both Naval Tactical Data System (NTDS) parallel and NTDS serial channels to support the interface requirements of the system. The processor communicates with the Command Response unit, the TOA AN/UYK-7, the keyboard printer, one channel of the tape unit, and the display processor using parallel formatted channels. The AN/UYK-7 and inter-AN/UYK-20 channels are equipped for 32-bit word transfers in order to support the anticipated message flow. An NTDS serial interface (10 Mb/s) is provided for communicating with an external source of data from either another MU in a driver mode or the Command and Control Center.

Display Processor - The display processor AN/UYK-20 also has its I/O channel set configured in both serial and parallel channels. The parallel channels communicate with the second channel of the tape unit, the AN/UYK-7, and the network control processor. The serial channels are used with the display and control station and the external connection for remoteing the display, operating with a secondary display station, providing the real time PLRS (RTPLRS) driver data to an MU, or communicating with the Command and Control Center. These external serial channels provide for communications up to 500 feet using the pair of coaxial cables furnished with the MU.

MU Peripherals - A minimal set of peripheral devices is required to support the MU processing subsystem. This set includes a cartridge magnetic tape unit and an I/O terminal which consists of a keyboard and a page printer. These peripherals are connected to the AN/UYK-20 processors through standard NTDS I/O channel interfaces.

The cartridge magnetic tape unit (CMTU) is a militarized unit nomenclatured the AN/USH-26 (V). This variable configuration device is a member of the standard AN/UYK-() peripheral set and can be equipped with from one to four cartridge tape drives. The unit requires four drives for the MU application to support program loading, map handling, UU library tapes, and data logging/recording. A typical application would find the library tape, the map tape, and two logging tapes in place. During program load, the map tape might be displaced.

This four-drive system provides a high degree of flexibility and the capability to operate with little or no loss in performance in the event of the failure of a drive unit. The cartridges are standard 3M DC300A units which provide up to 2.9 million bytes of data storage. The cartridges are considerably easier to handle and store than are tape reels.

The tape unit includes a two-channel multiplex capability which allows either of the two AN/UYK-20 processors access to any of the tape drives. This feature provides an efficient handling of data transfers without burdening the AN/UYK-7 with an I/O handling task.

The second unit in the peripheral set is the keyboard/page printer terminal. This militarized unit serves as an operator's manual terminal for processor control, message input/output, and listing/status printout. An important secondary function of this equipment is to act as a back-up for the system control capability normally provided by the keyboard of the display and control station. Because of this back-up role, the terminal is connected to the network processor rather than to the display processor.

3.5.1.2 The PLRS User Unit

The PLRS UU, shown physically in Figure 23, is a self-contained manpack occupying a volume of 0.29 cubic feet. Only through the extensive use of circuit miniaturization, in particular large scale integration (LSI), has this small size been attained. A total of 16 custom LSI chips are used in addition to the preamble correlator chips discussed in section 3.1.1 above. Their distribution in the user unit is stated in connection with specific functions below.

A functional block diagram of the PLRS basic User Unit (UU) is presented in Figure 24. Operation of the UU can be explained in terms of the processing done by each functional module. Most of the functions shown in the figure are not specifically separable into corresponding physical modules.

The following discussion of each UU function describes the processing aspects of the UU.

RF/IF Function - The PLRS RF/IF function performs frequency conversion, amplification, and filtering of the transmitted and received signals. During receive, this function also performs A/D conversion of the incoming signals in a 2-bit adaptive A/D converter, for subsequent digital processing by the Signal Processor Function (SP). During transmit, the digital output of the SP is used to generate the PLRS CPSM modulation in the RF/IF function. The UU crystal oscillator time base, frequency hopped synthesizer, and local oscillators are all contained in the RF/IF function.

Signal Processor Function - The Signal Processor function performs preamble detection/generation, interleaving/deinterleaving and error correction/error detection encoding/decoding of received and transmitted signals, PN generation, data correlation, time and phase detection/correction, TOA measurement and other functions required to

digitally process PLRS signals. The SP interfaces with the RF/IF function and the Secure Data Unit function (SDU). This function uses the preamble detection LSI plus 3 data correlator LSI chips.

Secure Data Unit Function – The Secure Data Unit function encrypts/decrypts transmitted and received PLRS signals, provides message validation encoding/decoding and alarm checking, and provides data for control of the PN generator, frequency hopping, and time scrambling. This function uses 3 of the LSI chips.

Message Processor Function – The Message Processor function (MP) contains a CMOS microprocessor that is the "brain" of the User Unit. This function controls and time-sequences (along with the Timing and Control function (T&C) working as a slave) all other processes done within the User Unit. The MP, additionally, generates, checks, composes, decodes, interprets and reacts to the PLRS link message set. The MP's microprocessor accomplishes most of the processing done by this function. A set of programs will be stored in each UU in the form of firmware. Each one of these programs will direct the UU to conduct a large number of sequential operations (i.e., receive, measure, record, transmit, store, receive, combine, transmit, etc.) over and over again. Thus the MU has the ability to place a UU in one of many modes to accomplish its required processing. The MP also interfaces with the Data I/O device, which could be a User Readout, Pilot Control Display Panel, or Special Data Module. This function uses 8 of the LSI chips.

Operator/Control Panel Function – The Operator/Control Panel function accomplishes the User-Unit-to-human-operator interface required to enable power, load cryptovariables, monitor operation of the UU, and interface with the antenna and Data I/O device.

Barometric Transducer Function – The Barometric Transducer function enables the UU to make measurements of barometric pressure and report this data to the MU, where it is converted to altitude information.

Timing and Control Function – The Timing and Control function generates all time slot timing signals used within the UU. Additionally, the T&C function generates all the sub-time slot signals, and the enable and disable control signals required by the UU, as commanded by the MP function.

Power Distribution Function – The Power Distribution function contains the power supplies, regulators, power line filters and power switching (and sequencing) circuitry needed by the UU. This function is controlled by the T&C and operator/control panel functions and provides power to all the electronics within the UU.

The input/output device, not properly part of the basic user unit, incorporates 2 of the LSI chips.

4.0 Unit Volume and Power Comparisons

Contrasts in overall size and power consumption of the PLRS and JTIDS units will be seen to reflect the differences in system requirements that have already been discussed. Figure 25 presents a summary of the volume, in cubic feet, and average power consumption, in watts, of three types of units, (1) the JTIDS terminals for the Boeing E-3A program, (2) the JTIDS Hughes Improved Terminal (HIT) under development for fighter aircraft, (3) the PLRS user unit. The circles in the diagram should be regarded as cross-sections of spheres whose volumes are correctly proportioned to represent volume or power.

The large volume of the JTIDS high power terminal for E-3A was allowed to permit a minimum technical and schedule risk development. The terminal is designed to provide functional modularity and is packaged in ATR boxes for airborne application. Now that the JTIDS terminals have been built, tested, and found to perform to specification, attention is being turned to size and cost reduction. Hughes has already developed and is under Air Force contract to deliver a new miniaturized design which provides the full capabilities of the E-3A terminal and is suitable for some fighter installations. Technology for this Hughes Improved Terminal (HIT) was discussed in Section 3.2 above.

Hughes is further reducing the size and cost of HIT by applying LSI and other miniaturization technologies to produce a simplified terminal for widespread fighter applications. The JTIDS Fighter Terminal will be reduced to the size and power levels shown in the second row of Figure 25.

The third row in Figure 25 represents the PLRS user unit. Its small size and power, even in comparison to the JTIDS Fighter Terminal, owes largely to the assignment of many of the computational functions to the master unit, as discussed previously. A second important factor is the relatively low frequency of message transmission and reception in PLRS vs. JTIDS.

Note that a large share of the volume and power in all 3 units is devoted to communications processing and signal processing (or signal and message processing). Now the JTIDS message transmission and reception load is much heavier than in PLRS. In particular, the JTIDS transmitter must be prepared to transmit in 900 consecutive time slots of the total of 1536 time slots in one 12-second cycle. PLRS, benefitting from the transaction group structure of time slots and a generally smaller work load, never requires a user unit to transmit more than once per 12 time slots, or receive a message more than every 32 time slots. From this comparison the heavier communications emphasis of JTIDS is evident. The JTIDS links can support digitized voice transmission, whereas PLRS obviously transfers relatively small amounts of data. In fact, the reporting and reception rates in PLRS are geared primarily to precise position location.

The small computational load in PLRS is distributed in time, so that computing can be performed by relatively slow circuits that consume small amounts of power. Even the peak demands on the power converter are reduced by the inclusion of a 6800- μ f capacitor to store energy for the transmission burst.

In modern TDMA systems the interplay of system architecture, waveform design, and hardware technology poses some very complex challenges which are new to the field of tactical radio signalling. Hughes, in PLRS and JTIDS, continues to demonstrate that systems can evolve to meet specific functional requirements within the tactical hardware size, weight, and power constraints.

5. References

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2. F. Amoroso, "Pulse and Spectrum Manipulation in the Minimum (Frequency) Shift Keying (MSK) Format," IEEE Transactions on Communications, (Corresp.) Vol. COM-24, No. 3, March 1976, pp. 381-384.
3. H.R. Mathwich, J.F. Balcewicz, and M. Hecht, "The Effect of Tandem Band and Amplitude Limiting of the E_b/N_0 Performance of Minimum (Frequency) Shift Keying (MSK)," IEEE Transactions on Communications, Vol. COM-22, pp. 1525-1540, Oct. 1974.

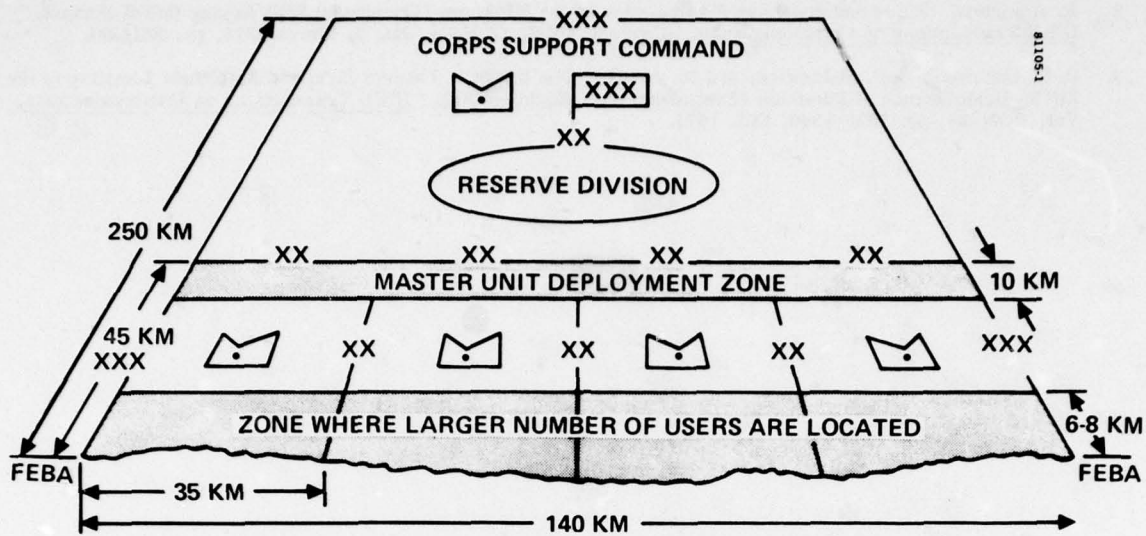


Fig.1 Typical army area of operations

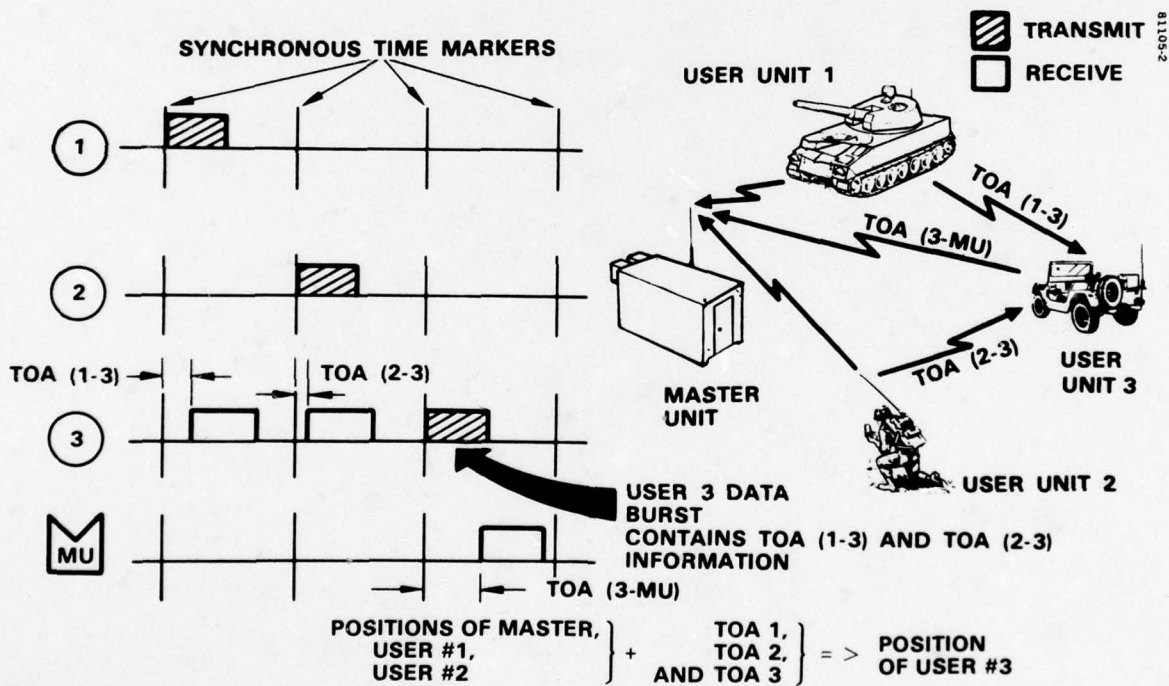


Fig.2 Simplified representation of multilateration in PLRS

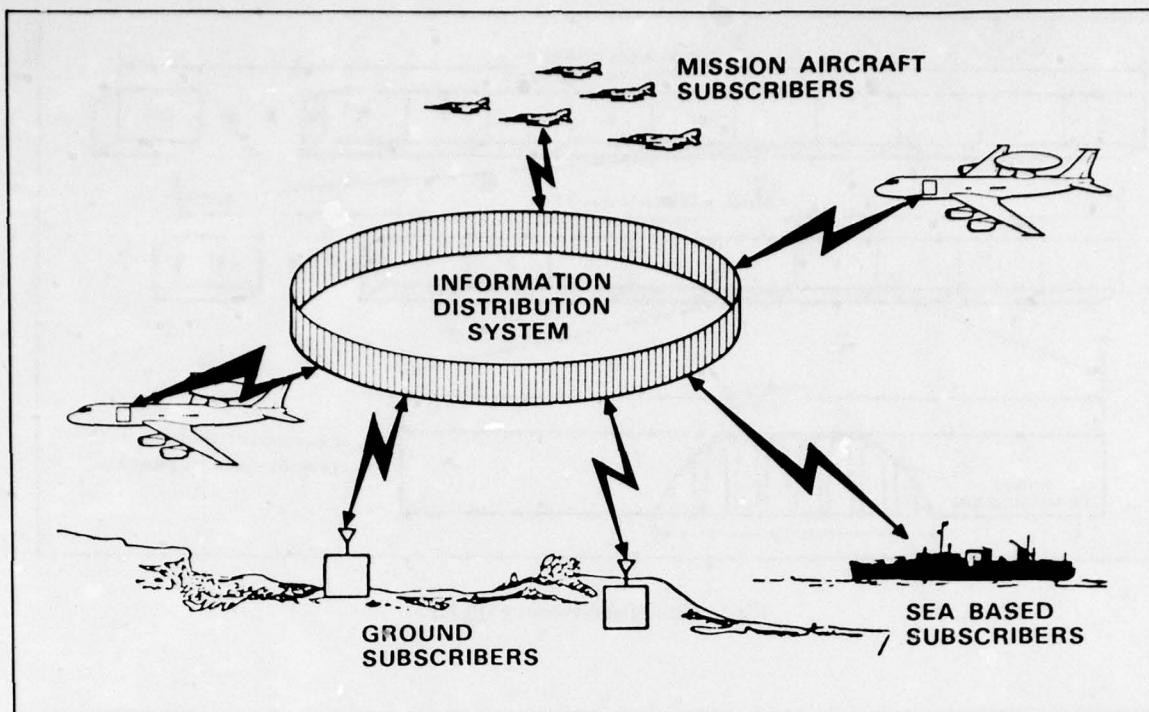


Fig.3 JTIDS information distribution concept

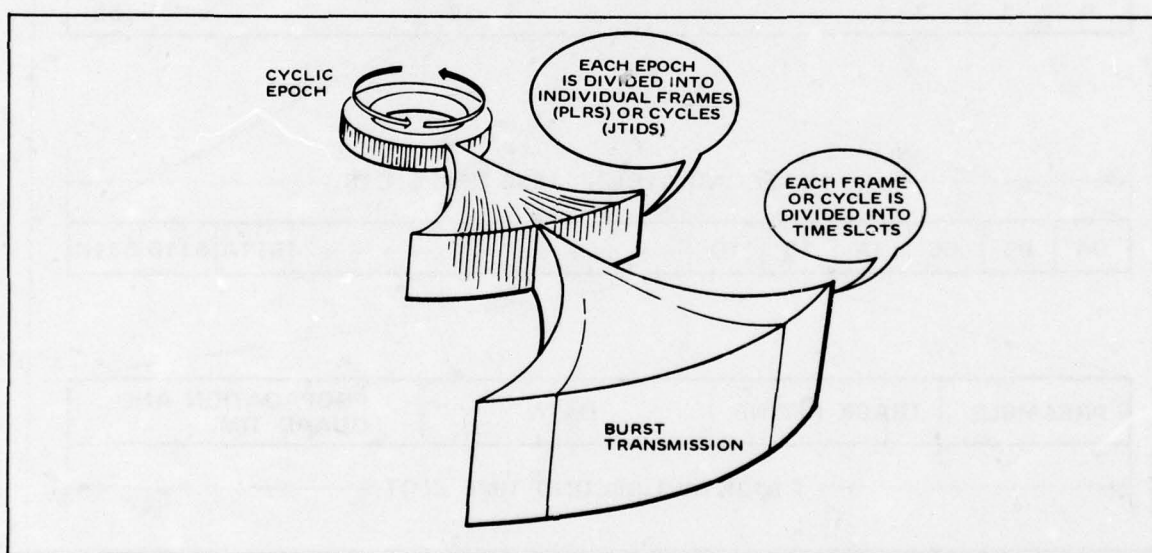


Fig.4 The cyclic timing structure of a TDMA network

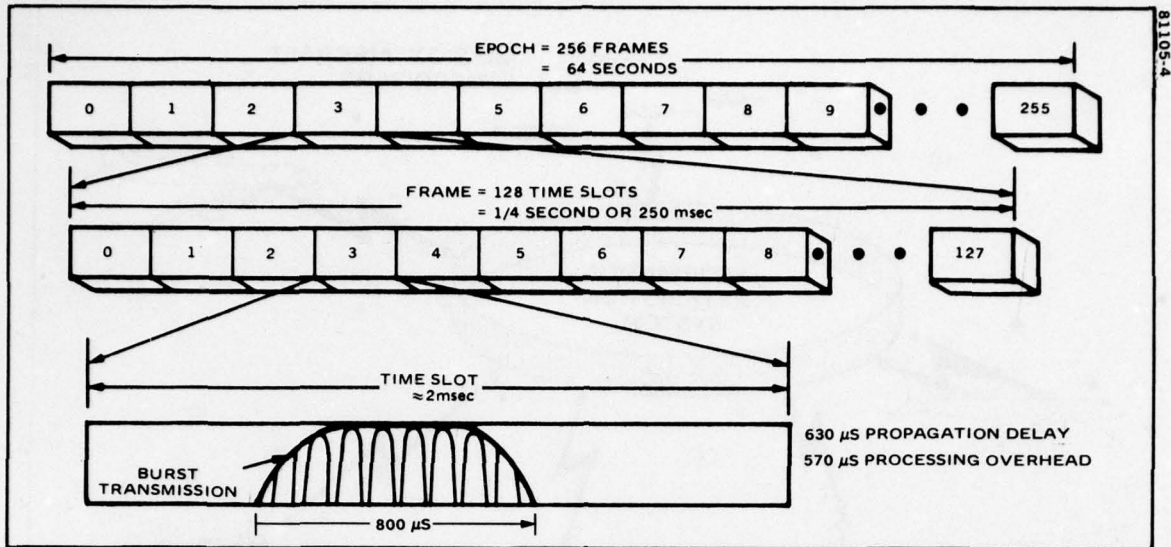


Fig.5 The time divisions of PLRS

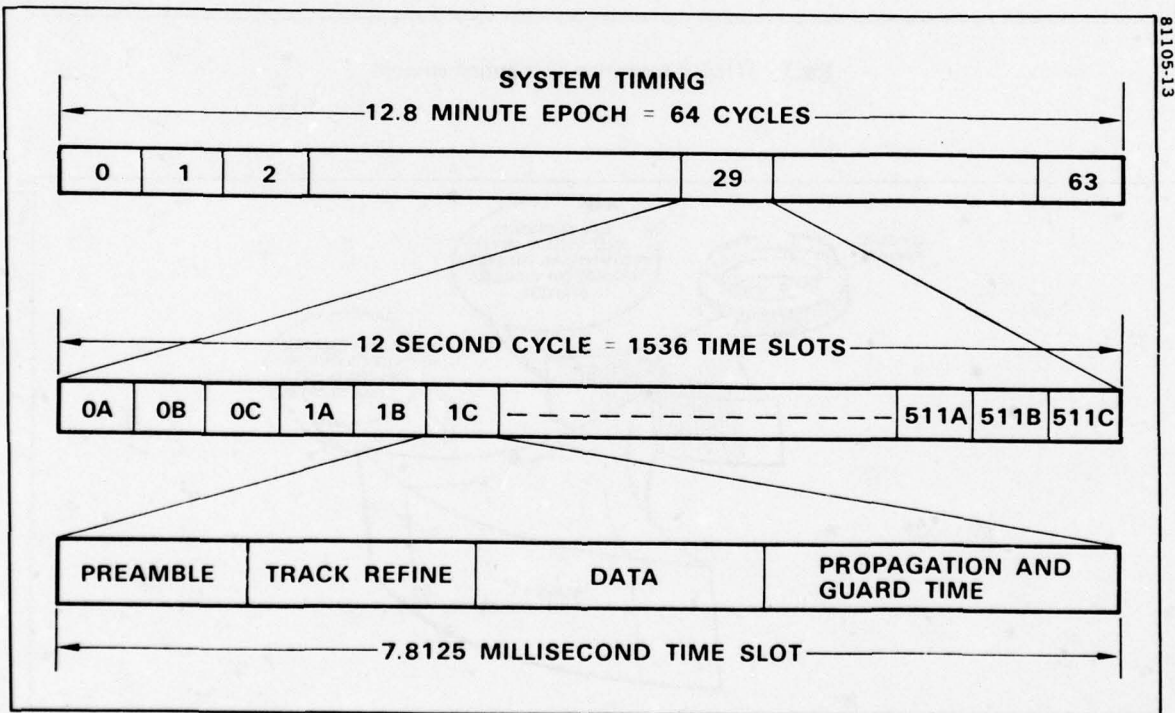


Fig.6 The time divisions of JTIDS

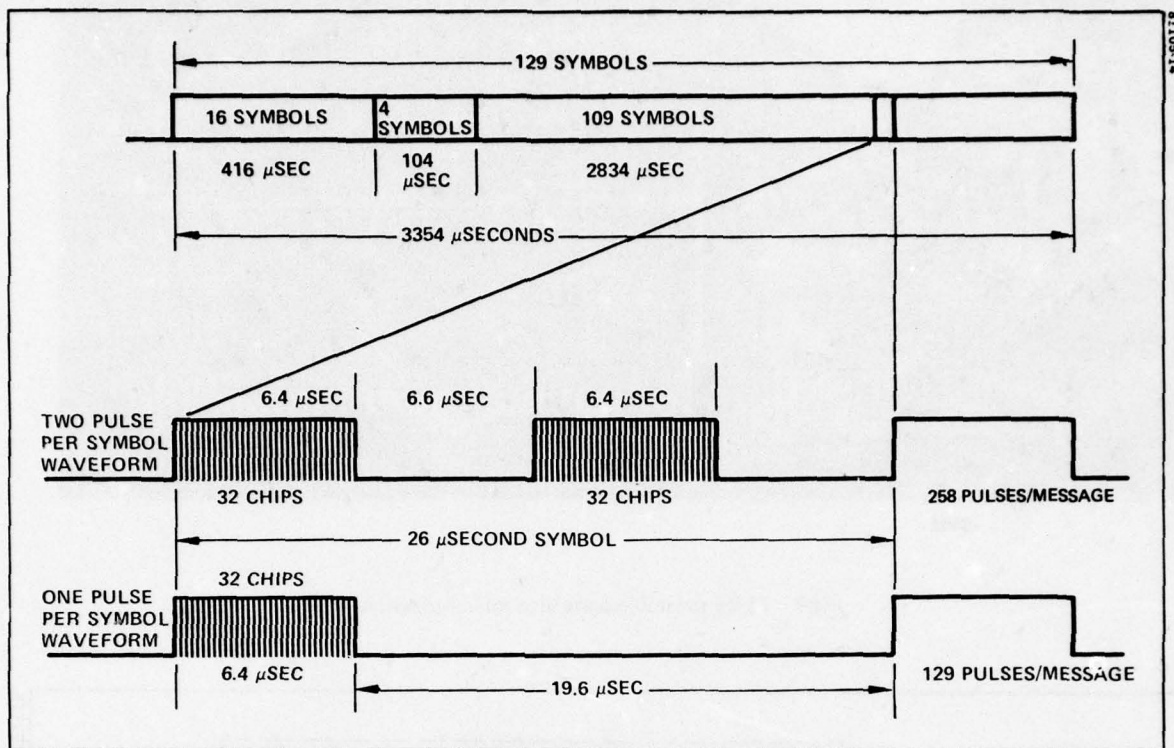


Fig.7 JTIDS waveform modulation

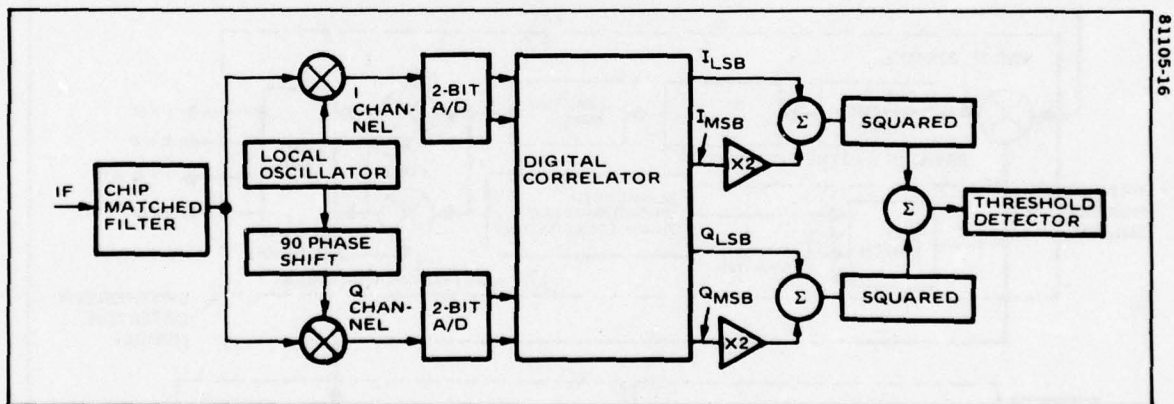


Fig.8 Model for the PLRS preamble acquisition function

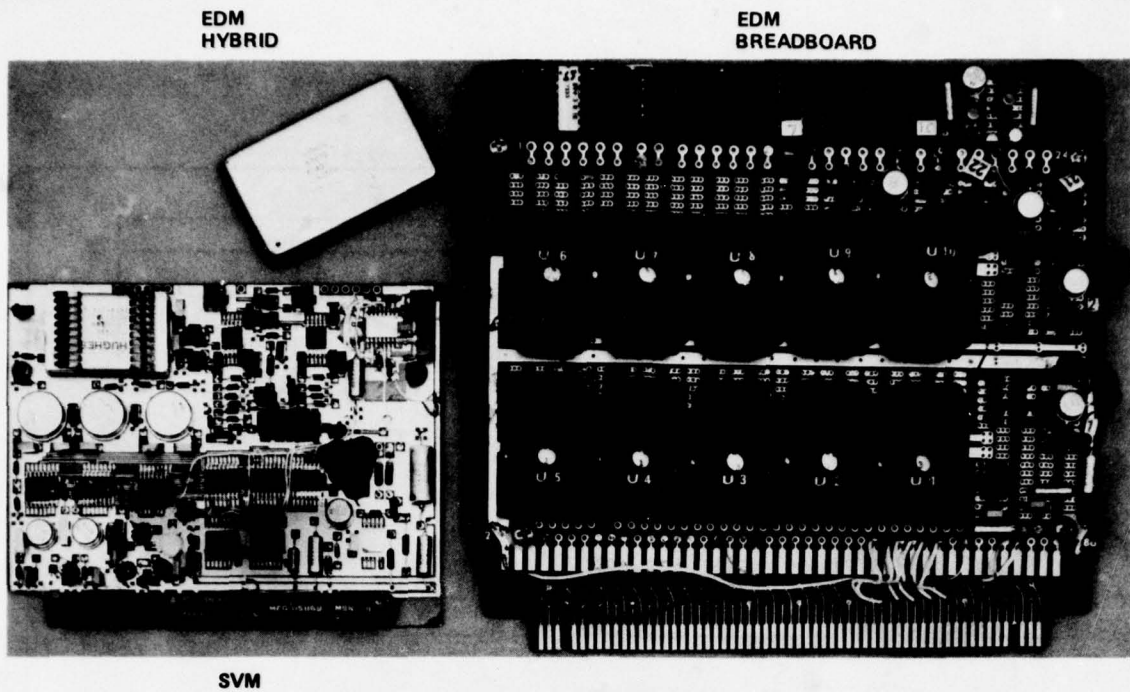


Fig.9 PLRS preamble correlator miniaturization

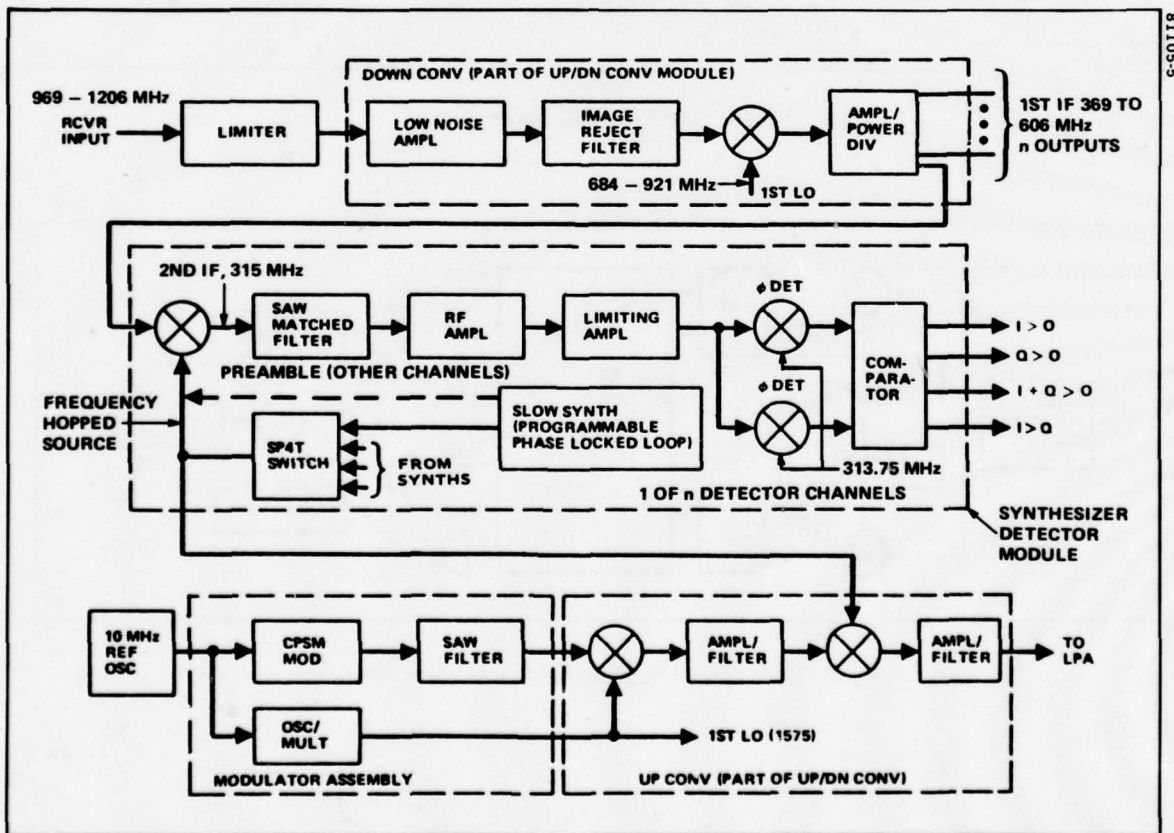


Fig.10 JTIDS transmitter-receiver simplified block diagram

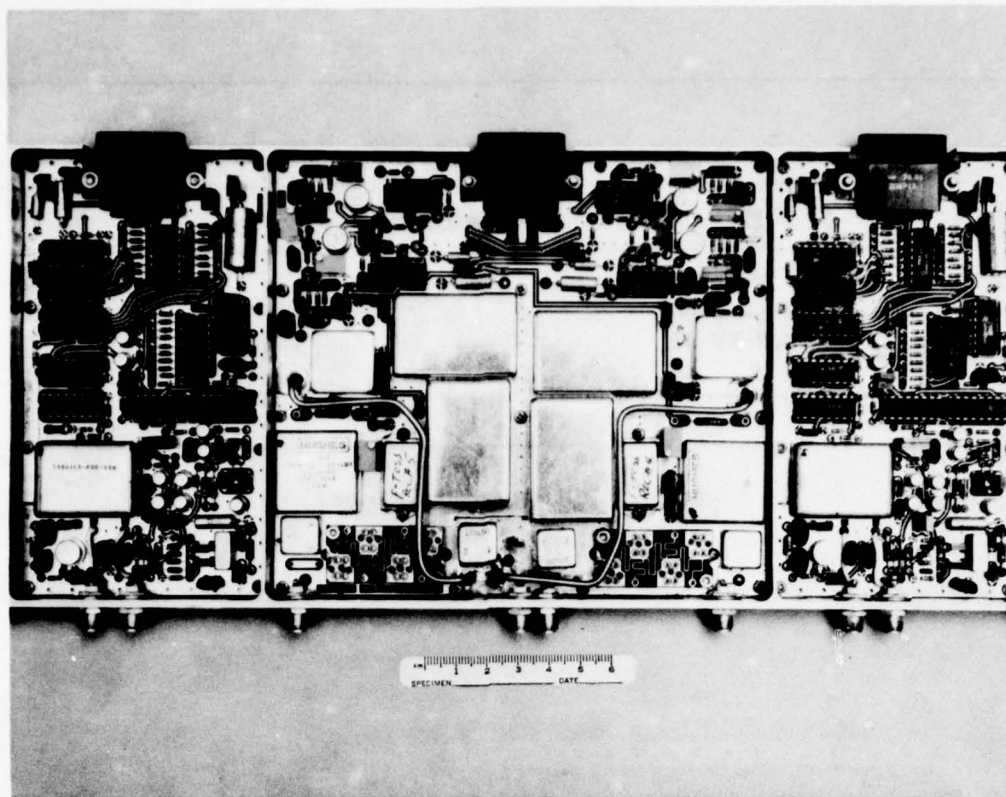


Fig.11 JTIDS synthesizer detector

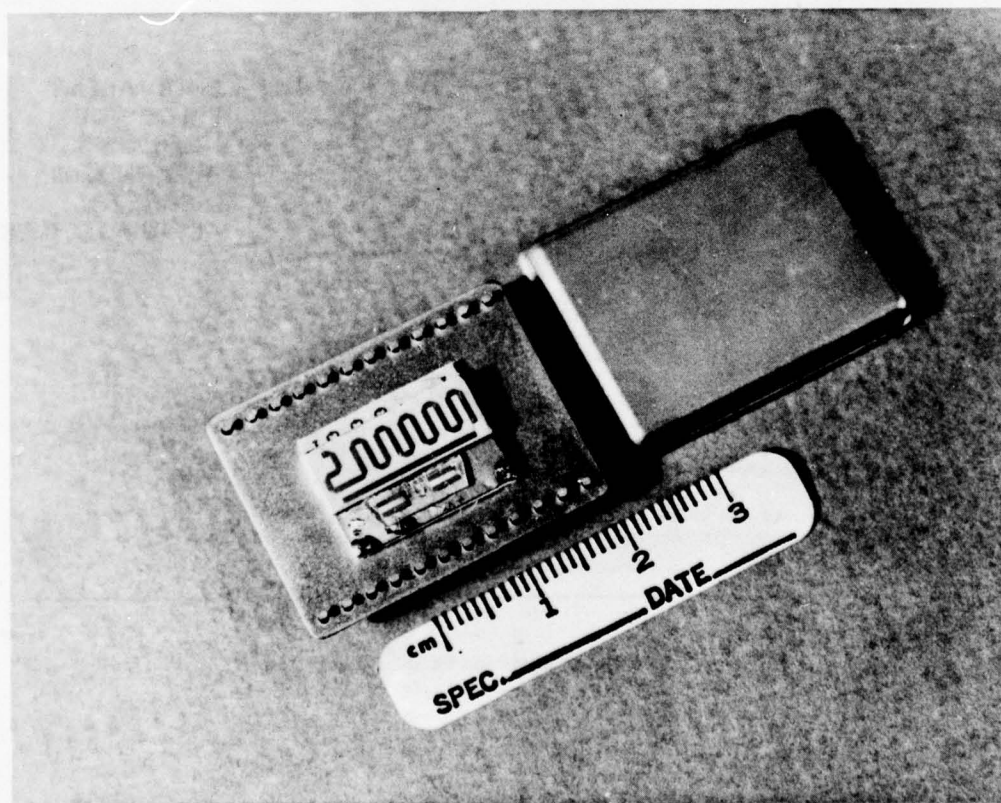


Fig.12 SAW device for oscillator application

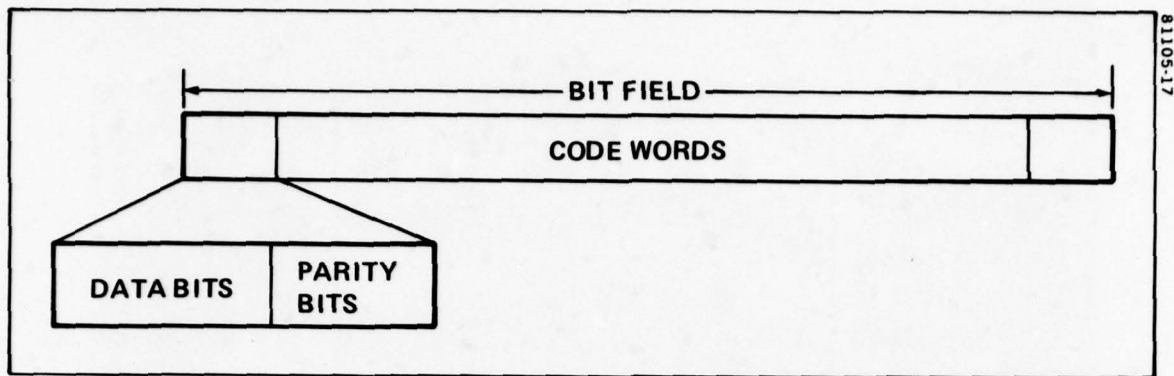


Fig.13 PLRS burst waveform structure

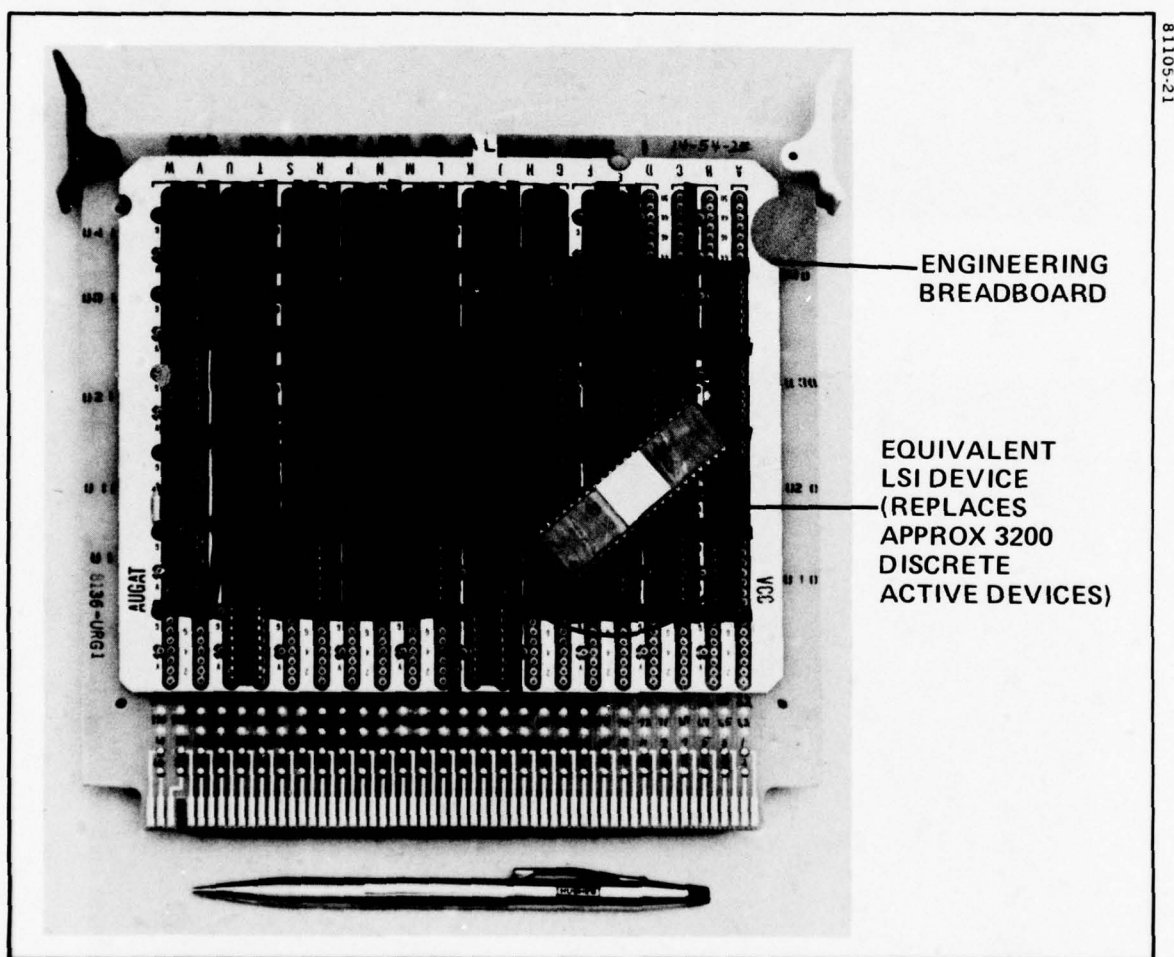


Fig.14 PLRS message validation circuit miniaturization

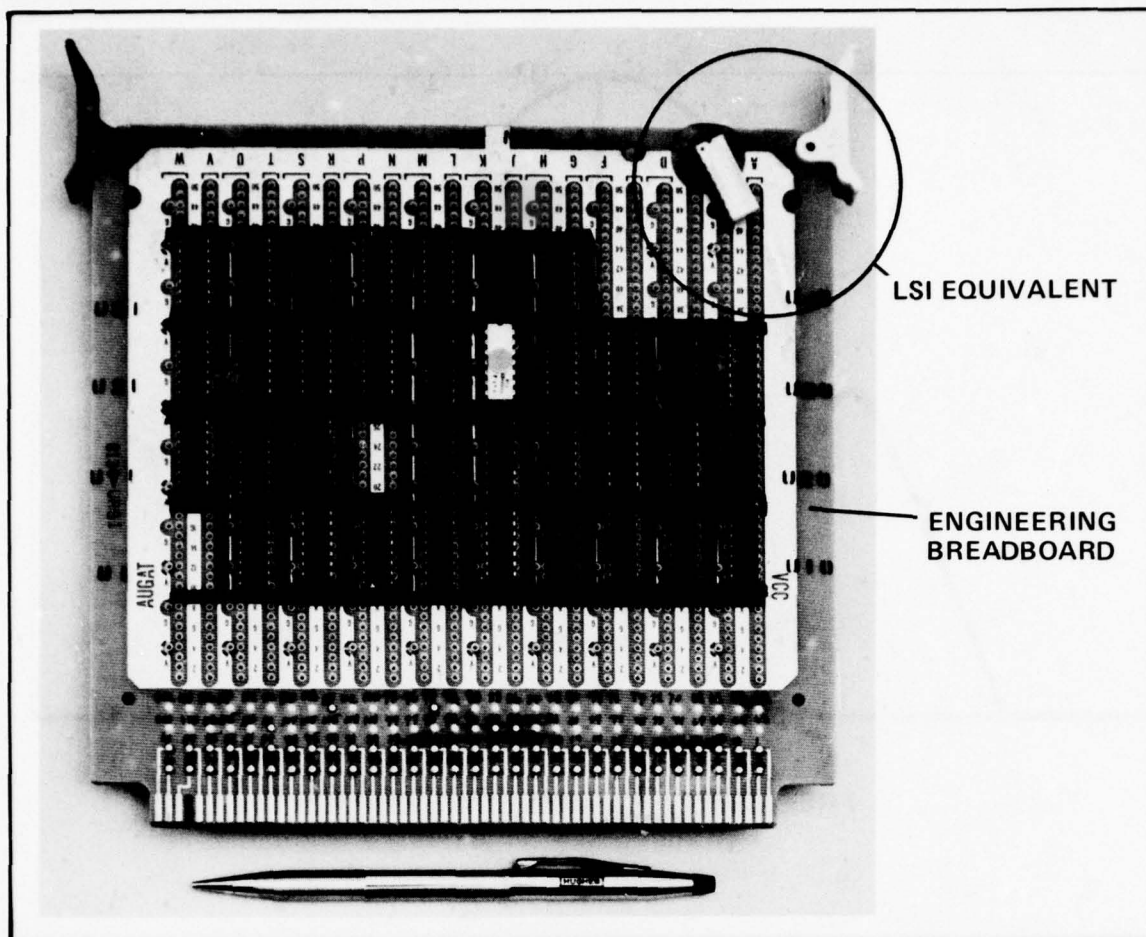


Fig.15 PLRS error correction circuit miniaturization

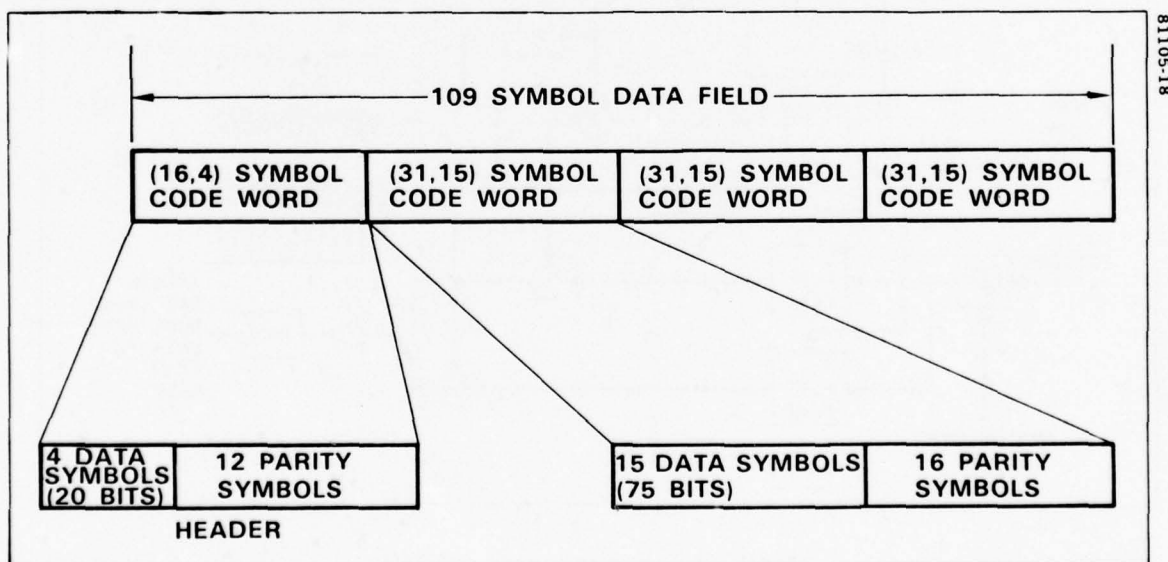


Fig.16 JTIDS Reed Solomon code structure

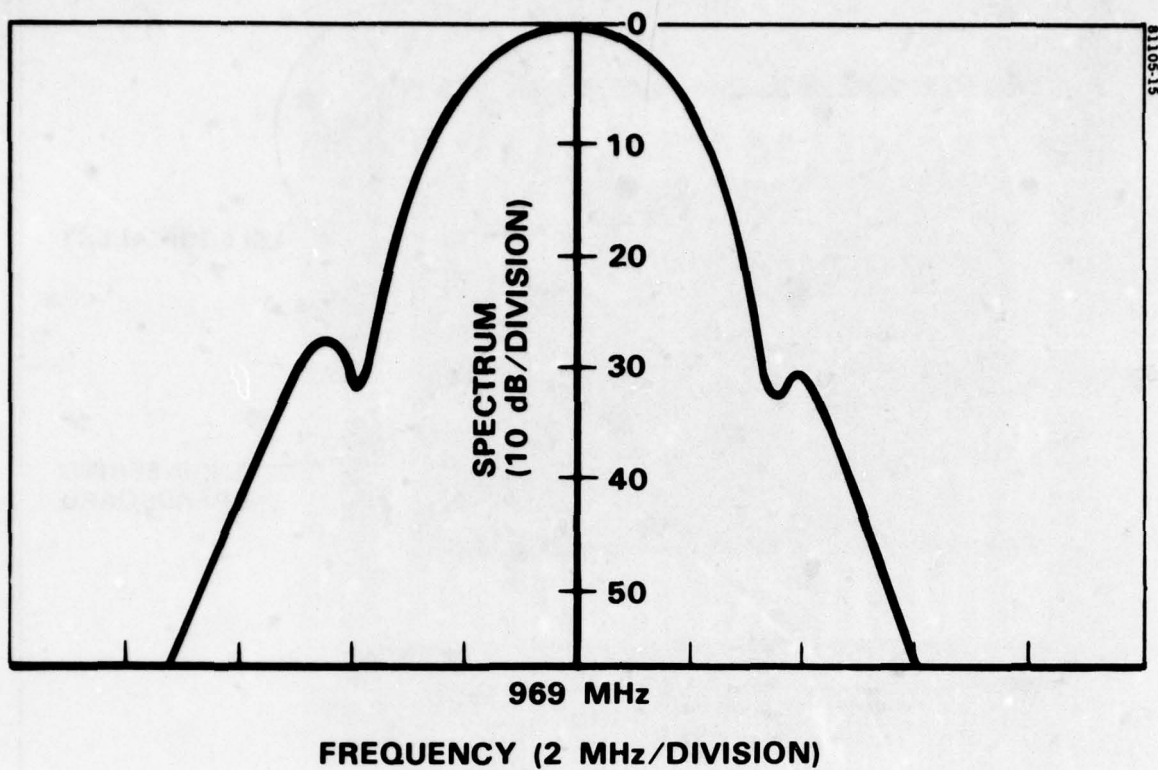


Fig.17 Instantaneous transmitted spectrum for JTIDS

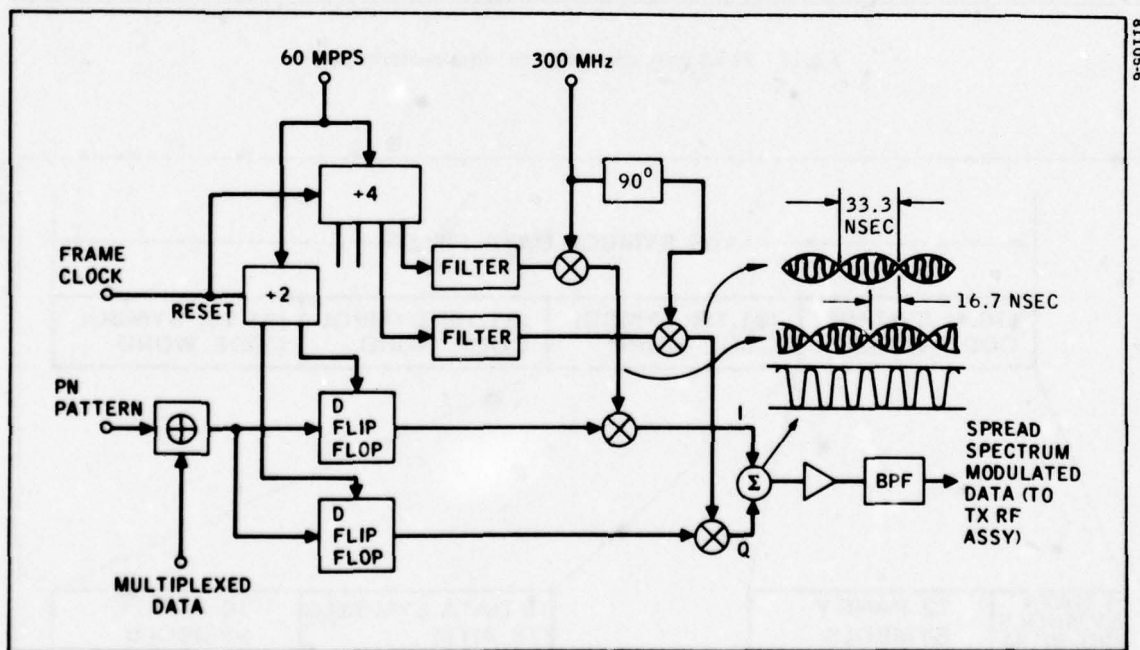


Fig.18 Early modulator circuit for CPSM

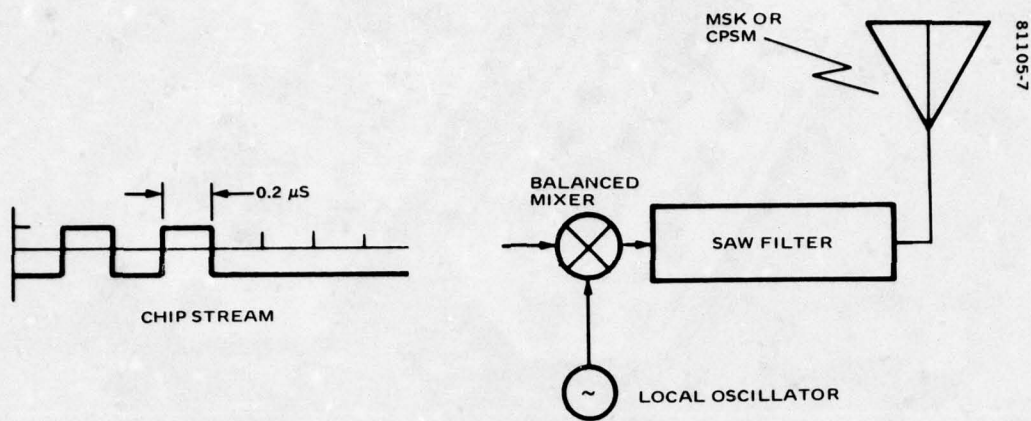


Fig.19 Simplified modulator circuit for CPSM

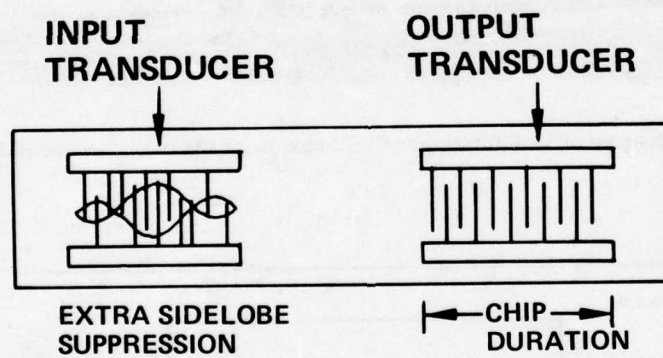


Fig.20 Schematic of SAW device for CPSM modulation

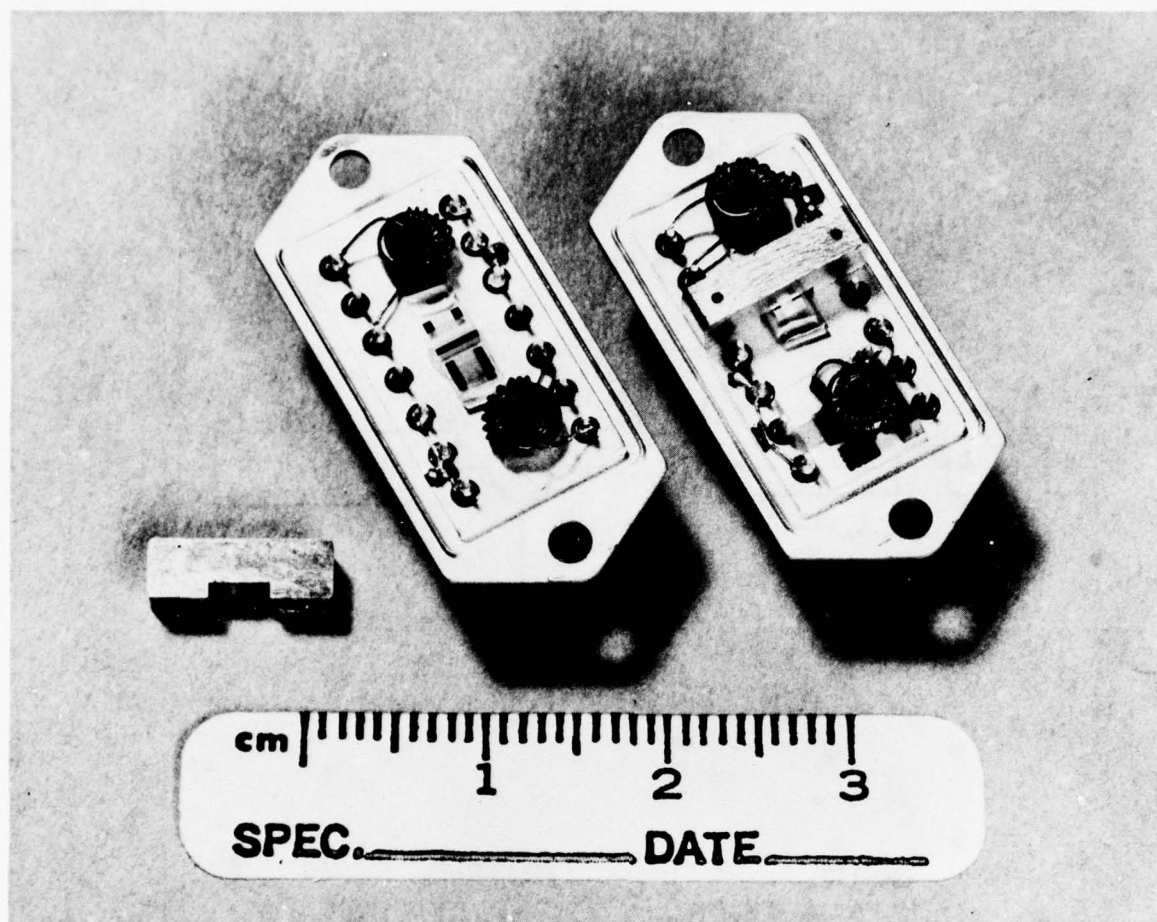


Fig.21 Photograph of SAW filters for a CPSM modulator and receiver matched filter

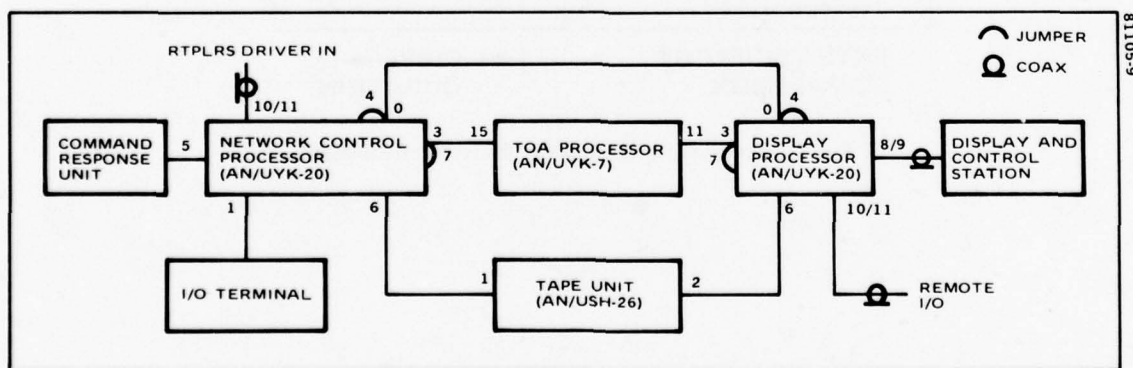


Fig.22 PLRS master unit peripheral interconnect block diagram

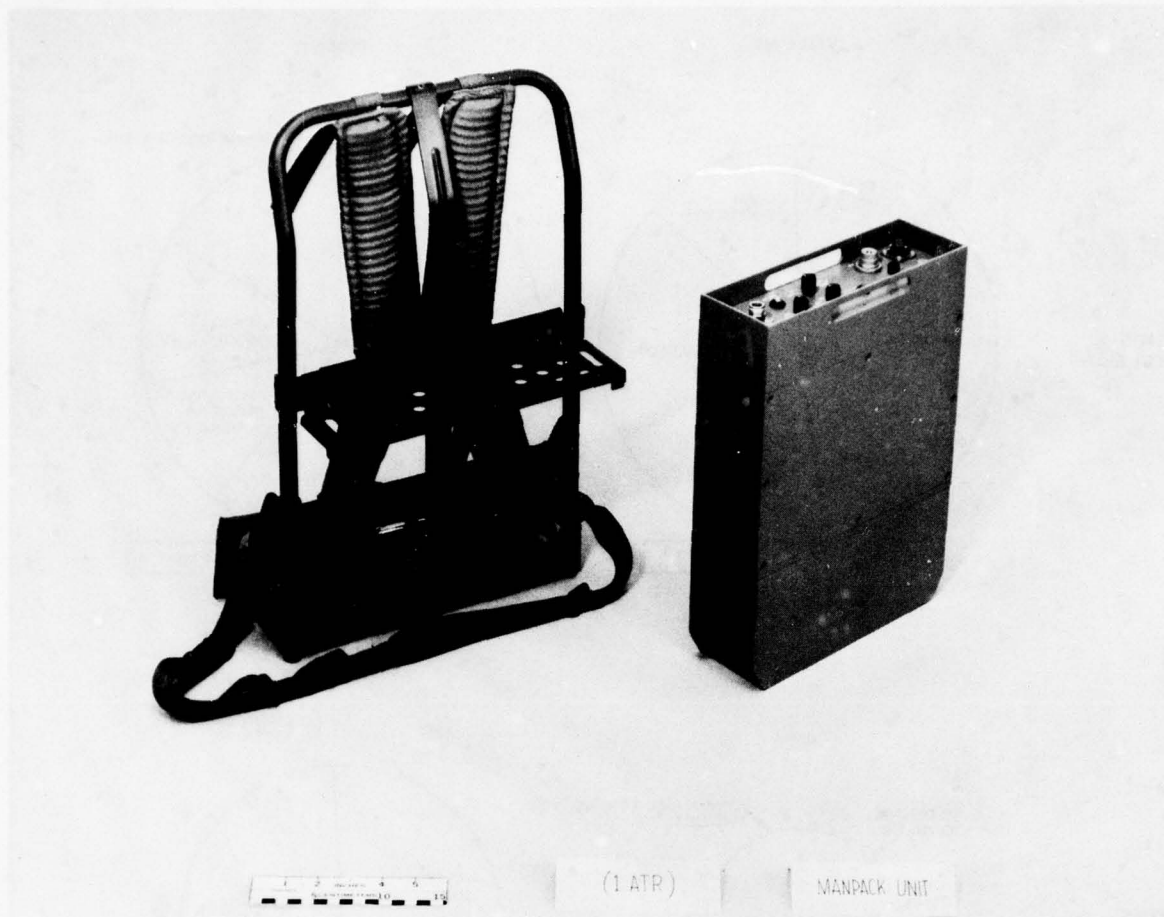


Fig.23 PLRS common basic user unit for manpack, surface vehicular, and airborne use

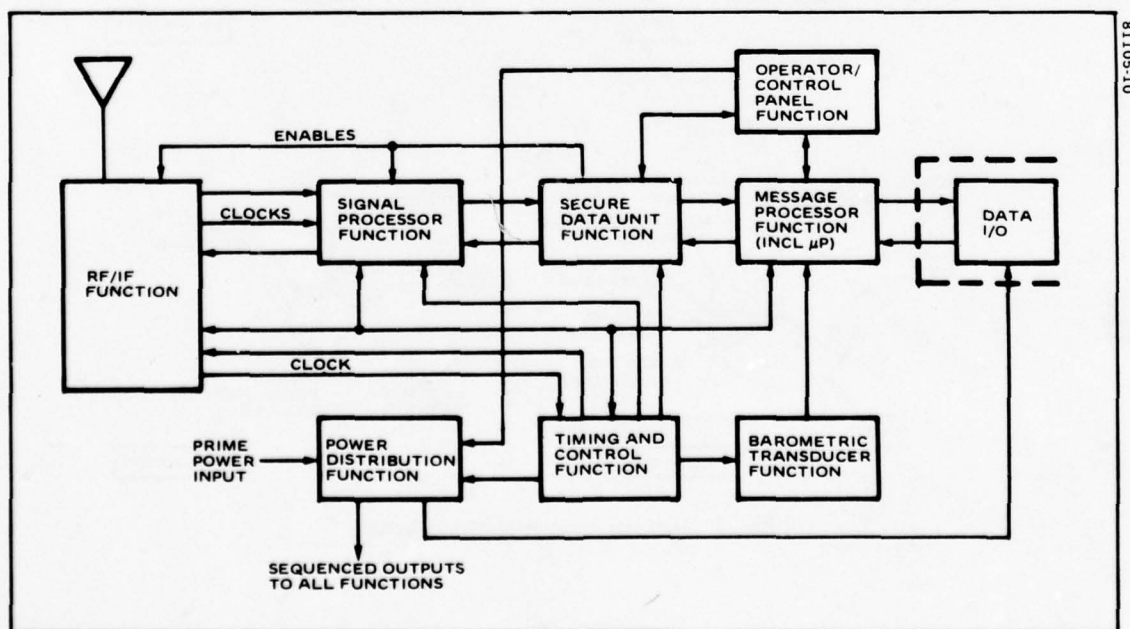


Fig.24 PLRS basic user unit functional block diagram

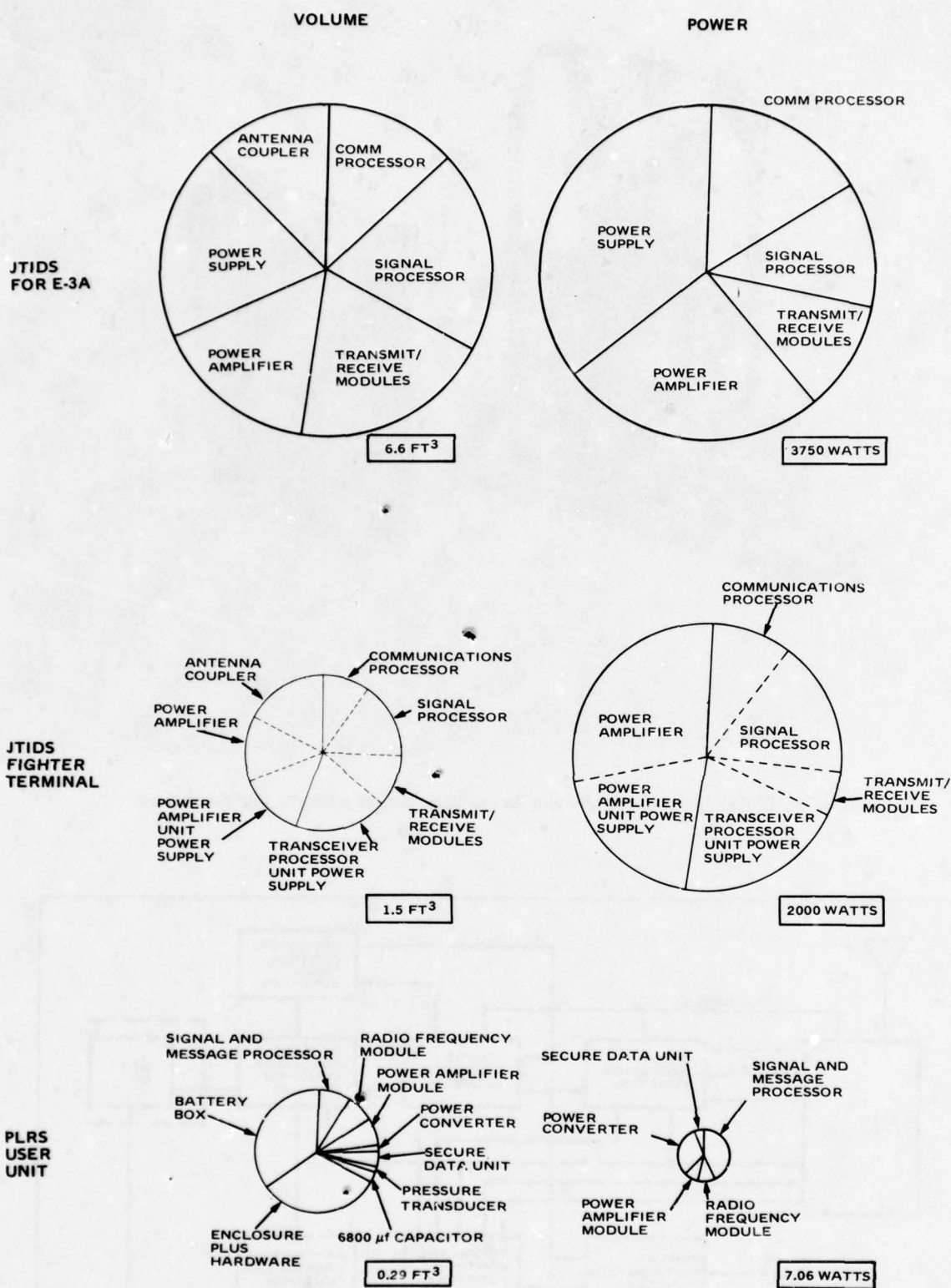


Fig.25 Unit size and power comparisons

DISCUSSION

M.G.Stansby

How are time slots allocated in JTIDS and PLRS?

Authors' Reply

In the PLRS system, each frame is comprised of eight time-interleaved transaction groups, consisting of 16 time slots each. This provides for structured information transfer between the master unit and sets of four user units, while providing adequate time between successive transmissions by a single user unit. Once a user unit has been assigned its user level, the user unit knows exactly when to transmit, when to receive, what processing is required and when to perform the processing. The transaction group structure also improves probabilities for receiving both outbound and inbound message traffic. In JTIDS the 1536 time slots in each cycle are divided into 3 interleaved sets of 512 slots each, as shown in Figure 6 of the text. Each epoch contains $512 \times 64 = 32768 = 2^{15}$ time slots of each set. Time slot assignments for transmission are generally made on the basis of 2^N time slots per epoch where N can vary from 0 to 15.

M.G.Stansby

How do the systems ensure that no two users use a time slot simultaneously?

Authors' Reply

In both the PLRS and JTIDS systems the usual network disciplines of a TDMA system apply. All users enjoy the exclusive use of time slots assigned to them. The one possible exception is during net entry in PLRS, when the unit seeking entry must transmit a special type message (called a user RAPID report) which indicates that the particular user is seeking entry into the network. It is possible that such special messages may be transmitted simultaneously by two users seeking entry into the network, but the message structure is such that such simultaneous occurrences will not disrupt normal network signalling.

F.Diamond

Are there any plans for interoperation of the two systems?

Authors' Reply

Yes, the Army has funded Hughes Aircraft Co. to further define and evaluate a system which integrates PLRS and JTIDS to satisfy the Army's data distribution and position location reporting requirements. This effort, called ADDS Mk 1, is directed at assessing the design and feasibility of combining PLRS and JTIDS to that end.

MULTI-FUNCTION COMMUNICATIONS

AND

TACTICAL DATA LINKS

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SUMMARY

DME and video guidance for tactical, unmanned vehicles operating in an EW environment place a multiplicity of requirements on the communications data links used for command control. Anti-jam, multiple access, variable bit rates, ranging, low probability of intercept and multipath discrimination are all necessary to achieve positive, real-time control. On top of this multi-functional capability resides the driving forces of low cost and effective spectrum utilization. By integrating temporal and spatial signal processing, the multi-function communications requirements can be generally met with moderate bandwidths. By proper design, fully adaptive transceivers with a single spread spectrum signalling structure can be derived with multi-mission capabilities. Such transceivers at moderate bandwidths are realizable by incorporating the new solid state, programmable, signal processing device technologies and microcomputer technology. The multi-mission capability leads to large transceiver production buys and standardizes the form, fit and function (F³) parameters. Moderate bandwidths with solid state implementation minimizes these F³ parameters. A single spread spectrum signalling structure leads to duplicity of circuits, increasing the use of mass production processes. All of these factors combined not only lead to low cost transceivers but also to lower overall vehicle costs.

1. INTRODUCTION

Tactical data links for the command and control of manned or unmanned vehicles, operating in an ECM environment, present significant technological/economical challenges. The unmanned vehicle, particularly, presents a problem in which technology and economics are inextricably bound together into a classical "approach-avoidance" conflict. While the state-of-the-art in ECCM technology appears able to support immediate fabrication of the required data link equipment, the economics of the situation definitely requires caution be exercised in developing the data link specification. By economics in this case we can mean both physical factors and spectrum utilization, in addition to cost. However, physical factors are so interrelated with cost, for instance, aircraft modification and integration costs often comprise 50% of the cost of an air borne system, that we will restrict ourselves to cost and spectrum utilization, the later being of great concern in the dense NATO environment.

As an example, with the availability of gigabit modem techniques, it would appear possible to build an anti-jam video (imagery) data link with large jam resistance for weapon guidance. The desirability of such a link is without question. At the same time, however, we are faced with the desires to incur as low a cost per weapon as possible, because of the expendable nature of the system as well as budgetary constraints and to utilize as small a bandwidth as necessary, because of the realities of frequency allocations. The conflict here is quite obvious.

Expendability, however, is not the only factor which impacts economical considerations. Expendability is related to offensive or strike missions and is relevant whether the guidance is by DME or imagery. When one adds surveillance and reconnaissance missions to the list of tactical data link applications, the impact of vehicle cost takes on added meanings. First of all, because all three are different missions with some different command and control requirements, the tendency has been to design special data links for each of the missions and, in some cases, to design a special data link for each type of air frame assigned to the same mission. This has led to the now much criticized "proliferation" of data links, and the popular thought that vehicle costs and hence the impact on the budget could be reduced if the number of types of data links could be reduced (i.e. mass-production). While there is room for direct cost reduction arguments in this line of thought (e.g. size of the cost reductions for a limited buy when compared to commercial volumes and resulting impact on performance), it has resulted in a second level of proliferation based upon mission also. By reducing the number of types of data links, for example, to a command link, a DME guidance link, an imagery guidance link and a small number of prime mission equipment links, particular missions could be satisfied by combining the standard links. This approach, however, results in a requirement to accommodate a multiplicity of possible on-board data link equipment. As an example, a particular airframe may, in one case, be required to accommodate a DME guidance data link with associated RF equipment. Video guidance is then achieved by "adding on" a standardized video downlink package, increasing size, weight and prime power requirements above that of the standardized DME package. The effectiveness of this approach in reducing vehicle or weapon cost is questionable. While the approach may be a matter of necessity in the near-term, it certainly is not for the long term. There have been efforts for designing and implementing integrated waveforms (Kivett, J. A., Bowers, G. F., 1973).

2. MULTI-FUNCTION REQUIREMENTS

At the recent AGARD Avionics Panel meeting in Munich, Diamond et al reviewed the rapid progress in new signal processing device technologies and alluded to their integration into a fully adaptive transceiver which may provide some relief from this apparent conflict. However, before we get into this possible solution, we should examine the functions required of the data links for command and control of unmanned vehicles. These functions are summarized in Figure 1.

We wish to exercise real-time or near real-time positive control of the vehicle. The means of control

will be provided by an anti-jam, multiple access communications data link. In a great many cases this link will be operating over a line-of-sight, ground-air-ground channel and we must accommodate propagation anomalies, particularly multipath. Positioning or navigation of the vehicle can be accomplished by either DME (which then requires a ranging function) or by backlinked imagery. The final function, which may or may not be of concern for a specific mission is that of low probability of intercept.

We can define the problem then as the most economical implementation of these functions as possible. The approach we propose is the opposite of the separation of functions - it is the integration of functions. That is, we consider the totality of the C^3 functions as being a single function, and we make that function the sole and only responsibility of the data link. This approach is based upon a few simple concepts:

1. Communications is moving toward an eventual all digital format.
2. The emphasis on commonality and standardization of data link equipment is being extended to equipment and information/data message standards, with movement toward eventual NATO standards.
3. A single spread spectrum signalling structure can inherently satisfy all the C^3 requirements.
4. Technology will support reprogrammable signal processing.

The implications of these concepts are that the data link becomes disassociated with the user functions, that is becomes "transparent". We partition the data link at the user RF/Modem IF interface and at the modem baseband/user baseband interface and accept the realities of frequency allocations as well as the need to accommodate different types of users. However, we do not accept the fact that the data to/from the modem and the IF signal to/from the modem have to be different signalling structures for one form of guidance as compared to the other.

3. DESIGN STRATEGY

The separation of modem and data source/sink provides a great flexibility in the application or use of the modem. The same form of direct sequence spread spectrum modulation would be used on both the forward link and back link and the same keying rate used also. The suggested modulation is some form of weighted offset, quadriphase shift keying (QPSK) at an I and Q channel rate of 10 Mbps, giving a 20 Mbps overall rate. Weighted, offset, QPSK is an economical waveform because it concentrates in-band energy with low side-lobes allowing use of saturated linear amplifiers and close stacking when more than one channel is needed. I and Q channel operation at 10 Mbps is in the realm of CMOS LSI implementation and 20 Mbps would be a realistic allocation to obtain. Furthermore, using the same modulation on both links at a single keying rate means that the circuits in the controlled vehicle modem and control station modem are duplicative, reducing specialization and leading to even more use of mass production processes.

The control station and vehicle modems are block diagrammed in Figures 2 and 3. Review of the diagrams illustrates the transparency of the modems and the duplicity of circuits. The control station modem shows that ranging is an inherent property of spread spectrum systems, and can be accomplished independent of both the type of data and the demodulation process. As shown, two-way ranging performed at the control station, rather than one-way ranging at the vehicle, puts the range measurement unit (RMU) external to the modem. That is, the RMU is user equipment for those systems employing DME guidance. A more important implication is that the burden of RMU cost, size, weight and prime power drain is removed from the vehicle/weapon and placed in the control station, and fewer control stations will be required than vehicles/weapons.

In the DME case illustrated, the telemetry downlink from the vehicle would contain whatever data is necessary for reporting vehicle control status, while providing for the round trip DME ranging measurement. For those systems using video guidance, the telemetry downlink would contain the digitized video and the range measurement unit is simply not applied. This provides the control station with the cost effective capability of handling both types of systems such as day and night oriented weapons with the same data link equipment. However, since some vehicle status reporting is usually required, even for those with video guidance, multiplexing of the digital low rate status and the higher rate video data, as shown in Figure 4, results in a single RF transmission from the vehicle. In a like manner, for a DME system, other on-board, user oriented equipment could be accommodated by multiplexing with the status data on the downlink. The sufficiency of a single downlink RF transmission maintains low vehicle overall F^3 and cost factors, while not incurring any increase in probability of detection.

The 20 Mbps example PN clocking rate would place constraints on the amount of downlinked data. Full 525 line, eight grey-level digitized video could not be accommodated. However, as initially pointed out, affordable jam resistant video for expendable missions will most likely be based on data compression which provides sufficient resolution. Since good progress has been made in this area and we are directing ourselves to the long term, the availability of a sufficient data compression technique or techniques is assumed. Thus the range of downlink data rates would extend from status only (with maximum processing gain) up to a multiplexed maximum of 20 Mbps (no processing gain). The example in Figure 4 shows how processing could be shared and traded between status and sensor data. It should be noted that for those cases where the downlinked data rate approaches the PN clocking rate, adaptive antenna nulling may be the only protection available at the receiving control station.

While modem transparency seems feasible, at least within specific classes, there is the question of implementing the downlink data rate selectability. The selectability is not a problem for expendable vehicles. The downlink rate would be set at the time of manufacture for the particular guidance. Selectability would be handled differently for the control station and vehicles intended for non-expendable missions. As previously stated, we would like to have some control stations capable of handling either DME or video guided vehicles. For another reason, vehicles intended for non-expendable missions could become multi-mission by no more extensive a mod than changing sensor heads. Data rate selectability for these modems would be achieved by incorporating microprocessor control. Figure 5 illustrates how

microprocessor timing control could be used to implement a selectable, multiplexed data rate capability through control of the clocking. Of course, the fixed master clocking feature of the design facilitates this capability. Figure 6 shows that the control station would maintain control of the situation through mode control commands (sensor/status data clocking rates) to the microprocessor via the uplink itself. In the control station modem a microprocessor, similarly placed, would provide for generation of the selectable data rate message to the uplink modulator (by punched in commands for instance). In this manner, changing the downlink mode can be made even during the mission.

So far emphasis has been placed on the downlink, for obvious reasons, and little has been said about the uplink. From the point of view of vehicle control and modem/sensor control, a message oriented rather than a continuous bit stream uplink may be more desirable. This provides for the use of "canned" messages, taking full advantage of the microprocessor, and allowing for more meaningful error control by working with the total message rather than individual bit errors. Messages (or block) error detection with requested message repeating is straight forward to implement and provides positive control (emphasizing correct through-put of the total command). The size of the message and the rate of each command can be easily adapted through the microprocessor to satisfy the requirements of the various controlled vehicles. Again these instructions can be punched in at the control station prior to or during the mission, adapting the link to changing requirements. While not degrading the importance or vulnerability of the uplink, the message formatting is actually the only outstanding difference from a conventional spread spectrum data link approach. Figure 7 gives two example uplink structures. Microprocessor control of the clocking allows variability of the update rate, number of messages per update and number of bits per message. Therefore, the processing gain can also be varied. Furthermore, the functional separation of the modem and data source (e.g. transparency) with computer control allows for repeated messages if a message is missed at the vehicle or for redundancy if a message is particularly critical.

4. MULTIPATH

The above discussion has been limited to the transfer of data without any consideration of the channel. As noted, one of the "multiple" functions to be performed by the data link equipment is resolution of channel anomalies. Performance and cost can be greatly impacted by the characteristics of the propagation media, and poor weather is not uncommon in Europe. Of particular concern is multipath distortion, either discrete refractive (atmospheric) or specular (ground). A comprehensive treatment of multipath in the line of sight channel has been undertaken (RADC-TR-75-233; Bello, P. A. et al, 1973) and the general problem areas in relation to direct sequencing systems are:

- (a) Degraded error rates, loss of signal and reacquisition problems due to fading.
- (b) False lock onto strong atmospheric multipath and subsequent loss of synch as it disappears during flight path dynamics.
- (c) Ranging and Doppler uncertainties as they effect acquisition time and strategy.
- (d) Improper nulling by adaptive antenna.

As has been pointed out, however, (Patti, J. J., Roeder, A. W., 1975) if properly treated, the effects of multipath on correlation receivers can be minimized and in some cases its occurrence can be used to improve link reliability. Such cases for improvement occur when the parameters of the channel vary at a much slower rate than the data rate and the multipath is resolvable. By using a record of the channel developed in a smoothing filter, the energy in the multipath components can be combined into the detection process, instead of rejected as in conventional spread spectrum processing. The result is an increased signal to noise ratio with subsequent improvement in error rate. The observations have been equivalent at times to that obtained by error correction against multipath. It is significant that the improvement is obtained without an increase in spectrum utilization.

5. ADAPTIVE ANTENNA

Previous remarks have alluded to integrating adaptive antenna nulling techniques with the spread spectrum modem to achieve the total jam resistance of the design strategy. Adaptive antenna nulling is a processing which provides spatial discrimination against undesired signals. Conceptually this discrimination appears as in Figure 8. That is, via some algorithm, the normal pattern of a receive array can be adapted to place nulls in the direction of undesired signals while maintaining main beam coverage of the desired signal. The adaptation is achieved by control of amplitude and phase weights at each element in the array so as to optimize some performance measure. A good approximation is that for an N element array, nulls can be placed on N-1 undesired signals.

This form of processing is a subject all in itself and reference is made to several symposiums (IEEE AP-S, 1976; NRS Meeting, 1978). However, some general remarks will be made as they effect the design strategy. A generic processor is block diagrammed in Figure 9. The processing may or may not include interaction with the modem.

The simpler form of processing is without modem/array interaction. That is the processing is autonomous. An example of this case is the large signal suppression algorithm or power inversion algorithm. The adaptive processor attacks those input signal(s) above a certain threshold and attempts to drive these signals back down to the threshold in a reciprocal suppression manner. The spread spectrum processing gain then allows delineation of the desired signal. As straightforward and effective as such processing can be, it does not protect against main beam interference and requires adapting the threshold over the dynamic range of the desired signal.

The particular mission geometry will determine if main beam interference would be a problem. If it is, then a desired signal reference function is needed to discriminate amongst those signals appearing in the main beam. In these cases there must be an interaction between the modem and array processor. Such

interaction may be uniquely defined for each signalling structure and cannot be briefly discussed. As with the modem control functions previously described, the microprocessor provides the flexibility required for controlling the functions of the adaptive array in the dynamic scenarios considered. Adapting the threshold/decision point of desired/undesired signal, varying the integration or convergence time in the feedback loops in response to changes in the environment and implementing constraints on beam/null formation are several of the adaptive functions which could be placed under microprocessor control.

6. GENERIC TRANSCEIVER

The generic transceiver block diagram appears in Figure 10. It is obvious that the strategy of flexible, multi-function communications/modem transparency is based on the emergence of two technologies. One is microcomputers to execute the distributed processing for control of the multiple functions, the other is programmable signal processing.

Referring to the figure, the microcomputers reside in the timing and control block, with the double ended arrows indicating the distributed processing. Computational complexity and execution speed required would be matched at each of these levels of control. (Single chip microcomputer technology of the early and mid 80's should quite comfortably satisfy these requirements. It is projected that in the early 80's, 16 bit single-chip microcomputers will be available with 32K ROM's and RAM's, and speeds may approach 100 MHz in bipolar implementations. Random access memories themselves will be in the hundreds of thousands of bits sizes, with costs of 0.01 cents/bit. Isoplanar, silicon-gate implementations may provide 20 MHz operations at extremely low power drain.) Master control would be executed through a hierarchical architecture, implemented most likely in high speed bipolar technology. Memory speed and capacity, available during this period, will be sufficient to accomplish interprocessor communications. In addition to performance flexibility, distributed processing, effected in this manner, will yield graceful degradation rather than catastrophic failure.

The control levels in the adaptive antenna processor are illustrated for one channel. The technology employed to implement the channel is relatively straightforward. Control of the feedback loop integration time, in response to a changing signal environment, can be achieved either in hardware (by selecting amongst a group of filters) or in software. Desired signal/undesired signal decision threshold adaptation is achieved by control of the amplifier noise floor. Beam/null formation constraints are achieved through voltage controlled attenuators in the complex weight circuit. An example organization of this channel and its amenability to such control is illustrated in Figure 11, which shows a hybrid microwave integrated circuit implementation. Significantly, much of the information required to derive the control signals is developed in the modem, particularly the colored noise filter, and communicated amongst the specific microcomputers through the distributed processing procedures.

In the temporal processing area of Figure 10, the possible control levels are multitudinous, and we will only illustrate the technology base as it relates to some of the signal processing functions. Pseudo-noise, direct sequence code generation/detection for synchronization preamble and data jam resistance, data demodulation, smoothing, bandpass filtering, A/D conversion and frequency synthesis are all functions amenable to either surface acoustic wave (SAW), charged coupled device (CCD) or customized LSI implementation technologies. The emergence and progress of these technologies into communications signal processing has been reviewed recently (IEE, 1976; AGARD, 1977). While baseband and intermediate frequency circuits represented the majority of the subject areas, recent advances in magnetostatic surface waves (Collins, Owens, 1978) show promise for providing RF signal processing circuits also. Filters and delay lines, which will impact both the physical and performance characteristics of the transceiver, are within technological feasibility. Of particular importance, however, are multiple tapped delay lines with tap programmable amplitude and phase coding properties. It is the complete programmability of these lines, when coupled with the microcomputer, that leads to real time, adaptability of the modem and hence the transparent, multi-mission nature of the data link. Shown in Figure 12 are monolithic CCD and monolithic SAW programmable tapped delay lines. The CCD device is 32 chips long at 2 Mbps (RADC-TR-75-233) and the SAW device is 31 chips long at 10 Mbps (Hickernell, 1977). Both devices are monolithic MOS structures, have demonstrated serial or parallel combinations for increased processing gain and are being integrated with microprocessor control elements.

7. MULTIPLE ACCESS

While the multiple access aspects of the design strategy have not been addressed specifically, it is obvious from Figure 7 that the uplink message structure represents either time division multiple access (TDMA) or continuous broadcast multiple address signalling. In either case a portion of the "m" bits/msg would be used as an address which could also perform as synchronization preamble for TDMA. The impact in the controlled vehicle modem is minimal since the programmable matched filter can be time shared between the address/synch preamble detection and data despreading functions. The two cases illustrated in Figure 7 shows that variable multiple access control situations (i.e. number of vehicles under control) can be accommodated through microprocessor control of the number of messages/frame (N). In fact this adaptability can be accomplished in real time, if desired. A key feature of data link transparency as it relates to multiple access is that the addressing function may also be made a user function. That is the addresses may be generated external to the modem, as with the command data, under control of the command and control computer. This provides the control station the flexibility to prioritize messages within the update period (frame), adapting the uplink to each vehicle's, real-time command and control requirements rather than using a fixed format. The backlink for the DME only case is directly compatible with TDMA. This will maintain a single RF chain in the vehicle. There will be a reduction in the processing gain on the backlink from the single vehicle case. However, in tactical applications, the number of vehicles under simultaneous DME control will most likely not be large enough to cause a significant reduction. For video-only backlinks in tactical applications, the number of simultaneous video transmissions to a single control receiver should be such that code division multiple access (CDMA) will perform satisfactorily. CDMA is compatible with the design strategy and again a single RF chain in the vehicle will be sufficient. For missions requiring a mix of simultaneous DME and video vehicles, a second RF chain would obviously be required.

8. CONCLUSION

A flexible (multi-function) design strategy exists which leads to a "transparent" data link concept, capable of accommodating both DME and compressed video command and control requirements for unmanned vehicles. The strategy is based upon a single spread spectrum signalling structure, and, when applied to moderate signalling rates, can be implemented through advanced, monolithic technologies. The transparency concept further leads to a multi-mission capability within groupings of data rate requirements, increasing the possible equipment uses. The total effect in this case is to drive costs down by increasing the size of production buys and maximizing the use of LSI mass production processes.

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REQUIRED FUNCTIONS

- REAL TIME
- ANTI-JAM
- MULTIPLE ACCESS
- MULTIPATH
- RANGING/IMAGERY
- LPI

Figure 1 Data link functions required for C^2 .

CONTROLLED VEHICLE MODEM

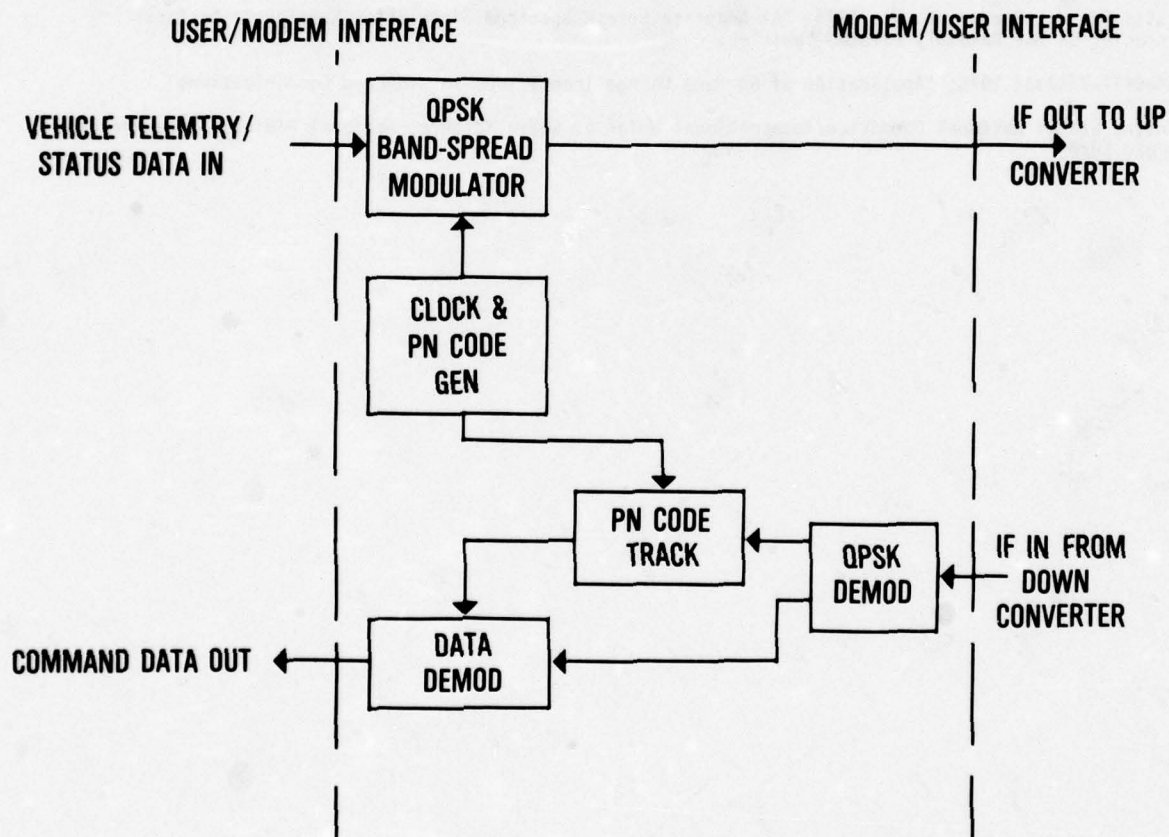


Figure 2 Transparent controlled vehicle modem block diagram.

CONTROL STATION MODEM

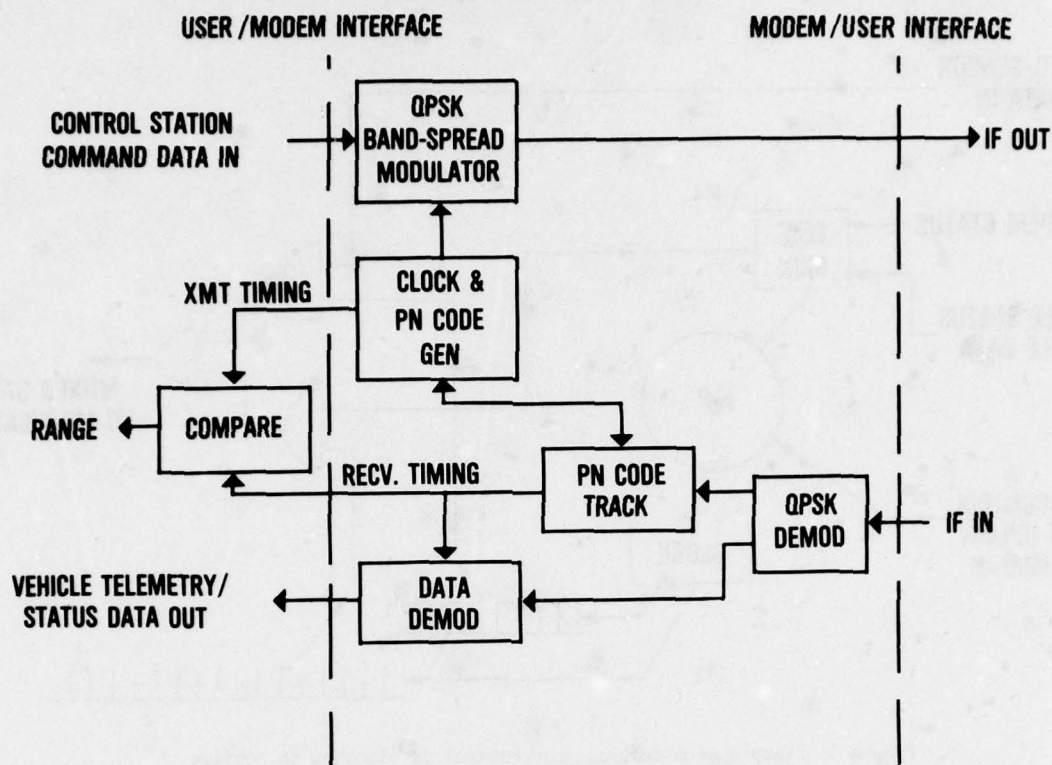
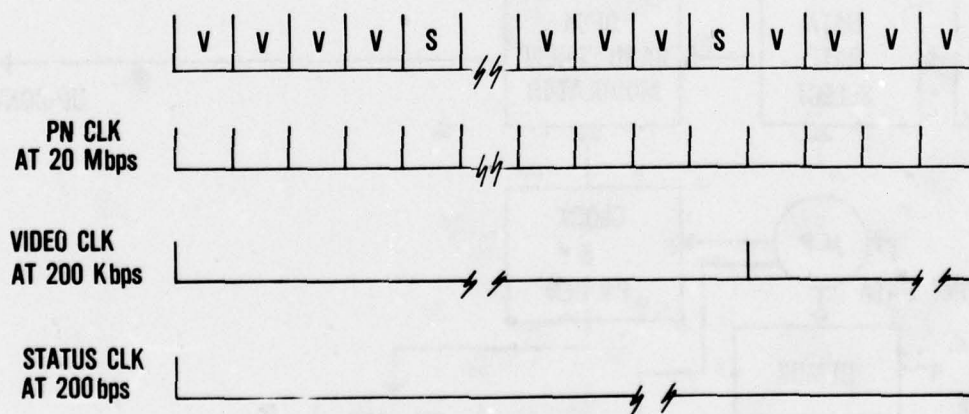


Figure 3 Transparent control station modem block diagram.

V & S MULTIPLEXING



$$\text{VIDEO PG} = \frac{16 \text{ Mbps}}{200 \text{ Kbps}} = 80 \text{ CHIPS/BIT} = 19 \text{ db}$$

$$\text{STATUS PG} = \frac{4 \text{ Mbps}}{200 \text{ bps}} = 20,000 \text{ CHIPS/BIT} = 43 \text{ db}$$

Figure 4 Example of multiplexing video and status downlink data.

SELECTABLE DATA RATE

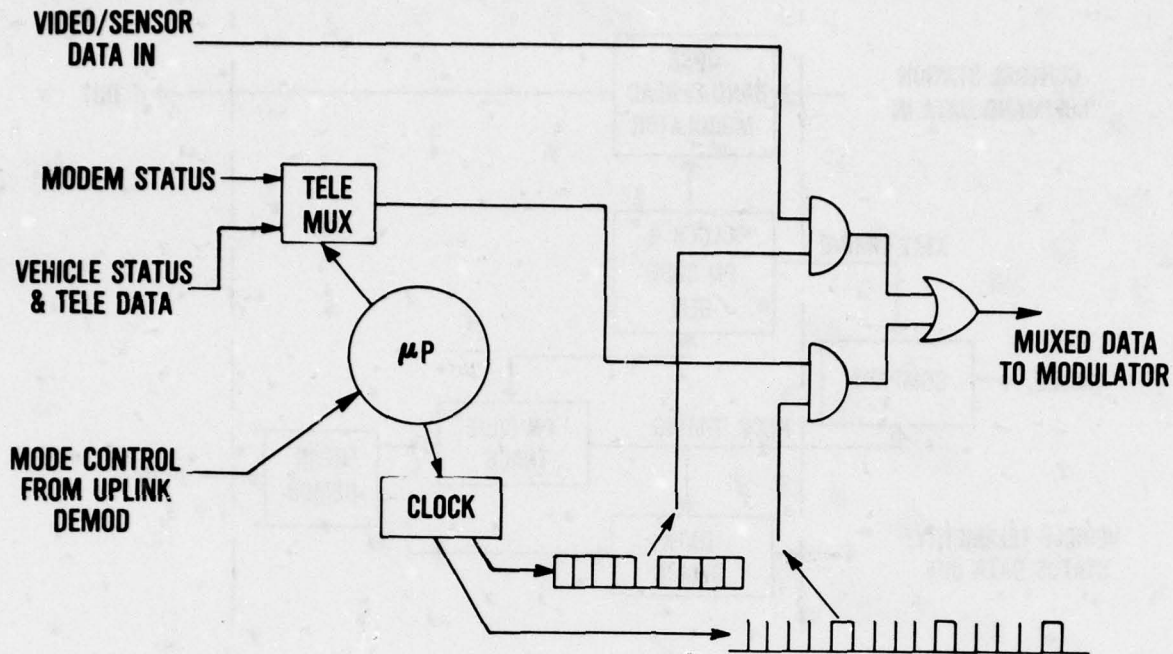


Figure 5 Example of microprocessor control of clocking to achieve selectable data rate.

CONTROLLED VEHICLE MODEM

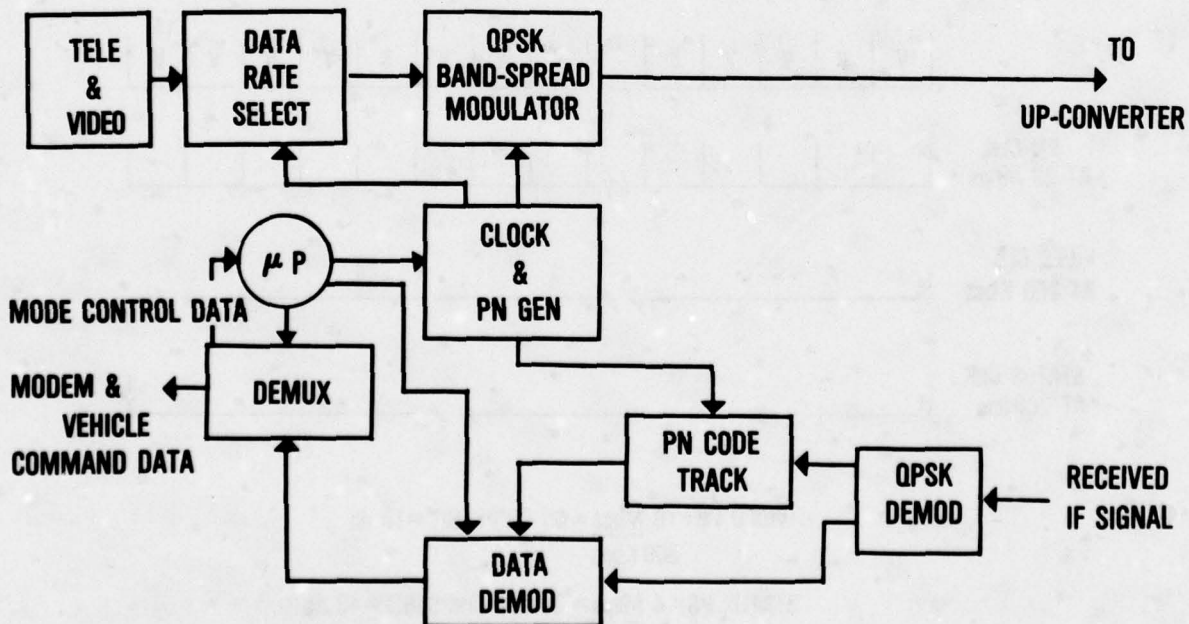


Figure 6 Mode control data from uplink provides commands to microprocessor.

FLEXIBILITY OF UPLINK

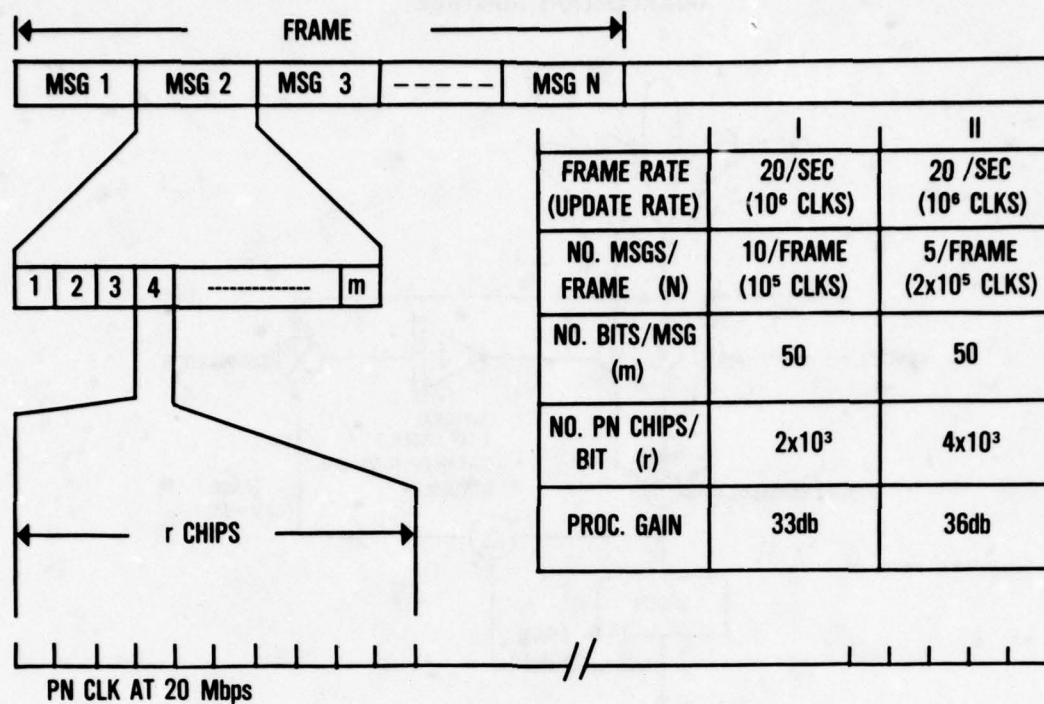


Figure 7 Example uplink structures showing flexibility achievable.

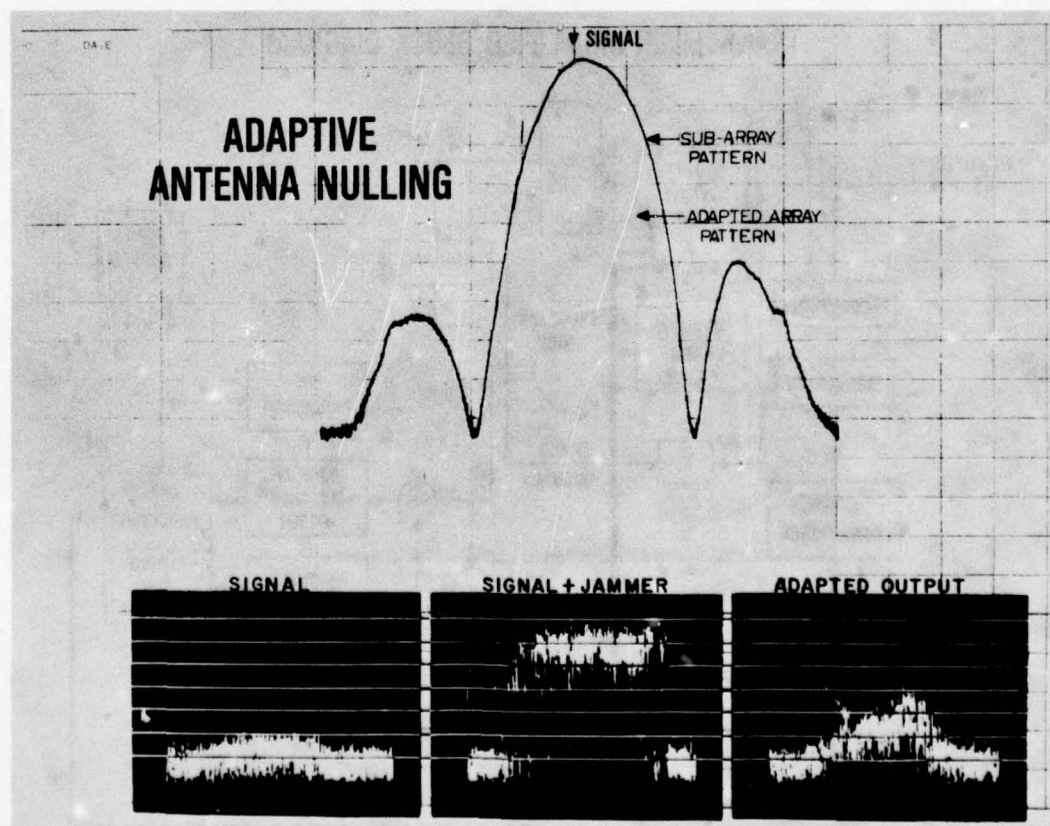


Figure 8 Adaptive antenna nulling pattern and processor adapted output.

BASIC TYPES OF ADAPTIVE OPTIMIZATION CORRELATION CONTROL

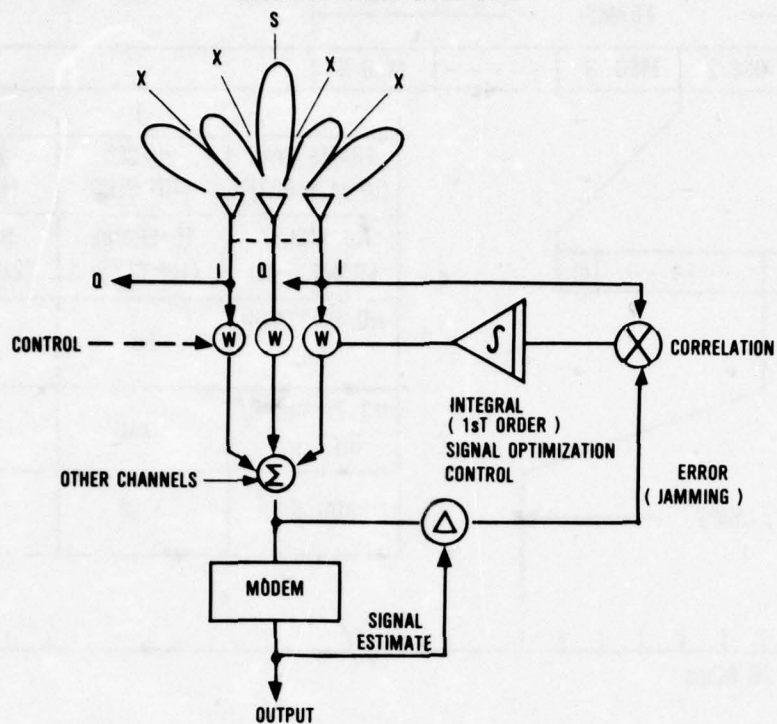


Figure 9 Generic processor block diagram.

TRANSCIVER SIMPLIFIED BLOCK DIAGRAM

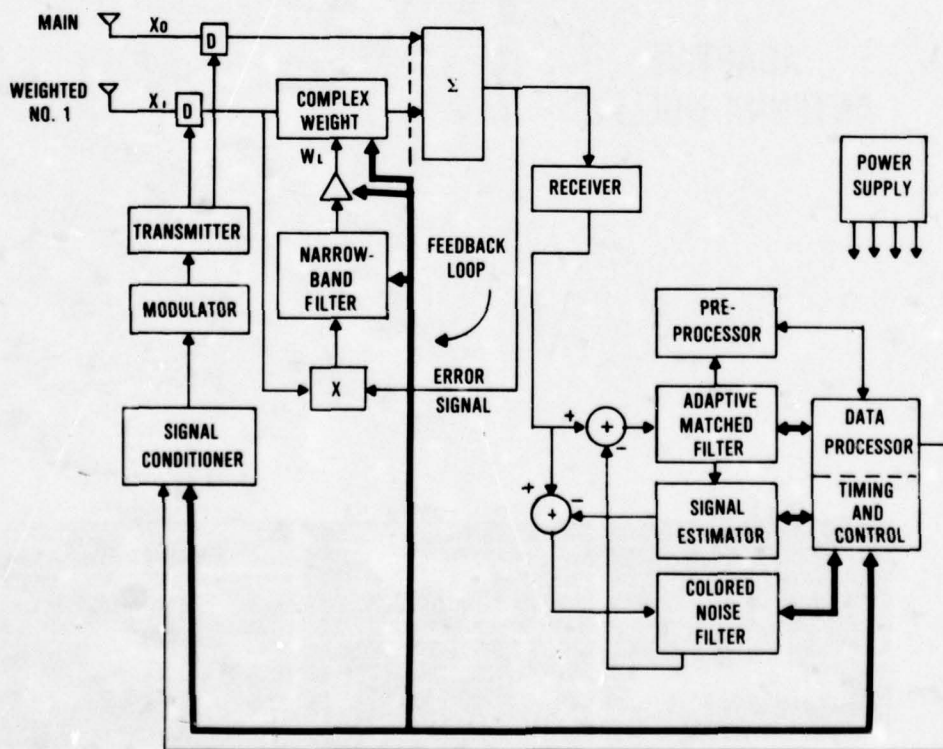


Figure 10 Block diagram of generic transceiver.

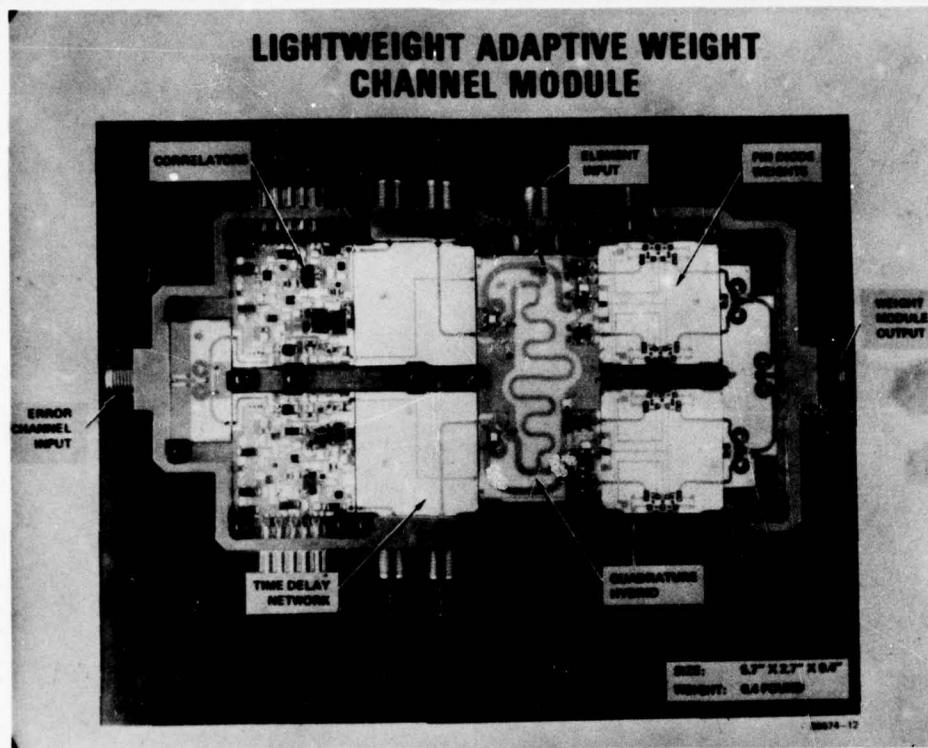


Figure 11 Hybrid microwave integrated circuit implementation of an adaptive processor channel.

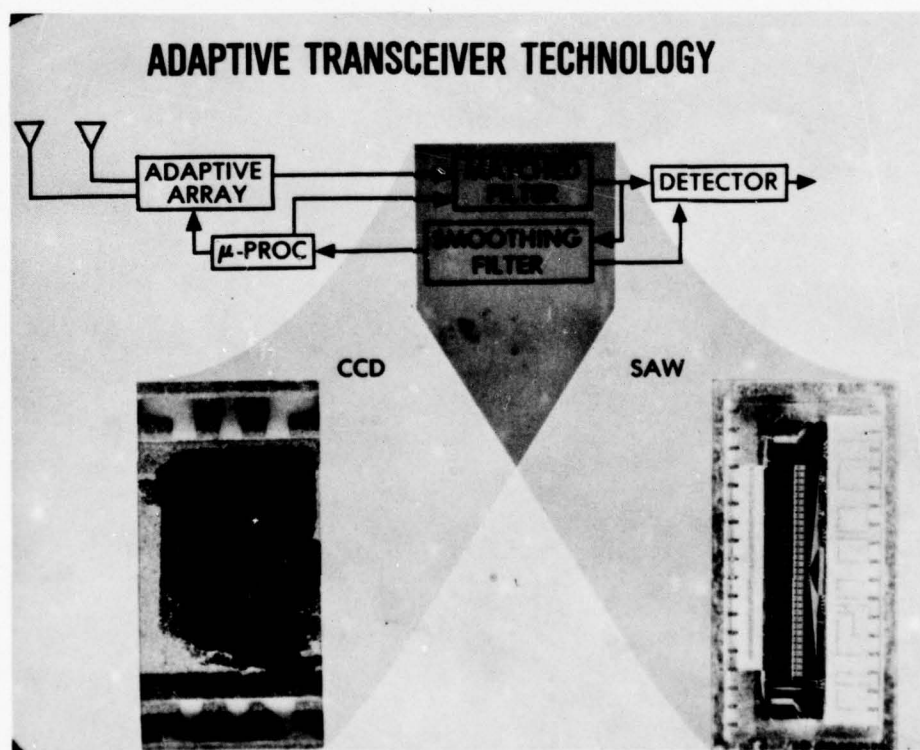


Figure 12 Example of monolithic CCD and monolithic SAW programmable tapped delay line technology

INTERACTION OF ANTENNA ARRAYS AND MODEMS IN TACTICAL DATA LINKS

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SUMMARY

The combination of spread spectrum signaling and adaptive array antennas is recognized to provide significant interference or jamming resistance. This paper investigates the effect of the antenna array on a wideband signal; of special interest is signal distortion produced by the nulls of the array. An analytical model is developed to relate array characteristics and the matched filter output for a wideband coherent receiver. The distorted output is written as the sum of the desired autocorrelation function and its derivatives. If the signal is being nulled, the derivatives can easily predominate and distortion become severe. Results are specialized to the case of a pseudo-noise (PN) - coded carrier "filtered" by a four-element linear array. A comparison with experimental data is made, and several conclusions regarding receiver design and signal choice are drawn.

1. INTRODUCTION

Adaptive antenna arrays have become the subject of considerable investigation in recent years. In a typical adaptive array, phase and amplitude of the signal at each receiving element are weighted before those signals are summed. The value of the element "weights" is determined by an algorithm which seeks to minimize the effects of an undesired signal (unintentional interference or jamming) in the array output. In their simplest and best understood form, these algorithms seek to minimize the total signal power output of the array. If the interference is much stronger than the desired signal, then the array will form spatial nulls in the direction of the interference; these nulls will have sufficient depth to roughly equalize the signal and interference power. If the modulation technique permits communication at unity signal-to-interference power ratio, then an adequate measure of interference rejection may be achieved. Of course, this type of adaptive array will also null the desired signal in cases where the interference is relatively weak or is absent; this effect often limits the usefulness of the technique.

A significant performance improvement may be achieved in cases where the desired signals can be electronically and reliably distinguished from the interference. The array algorithm can then avoid nulling the desired signals and can concentrate the resources of the array entirely on interference rejection. An especially strong synergism exists between spread-spectrum modulation schemes and adaptive arrays. Not only does the structure of the signal provide a reliable discriminant for the adaptive array, but the "processing gain" of the modulation technique provides interference rejection over and above that furnished by the array. Current technology easily permits the use of pseudo-noise (PN) phase-coded spread spectrum signals in combination with adaptive arrays, and recent experimental work [COMPTON, 1978] indicates that the scheme holds promise. Because of the complicated frequency dependence of array antennas, the practical combination of frequency-hop spread spectrum and adaptive arrays appears to be several years away.

The use of wideband signals with adaptive arrays raises several questions which must be carefully studied prior to implementing such a system. Of fundamental concern is the effect that the antenna has on the desired signal. Sophisticated receivers, especially those using matched filter or correlator detectors, can be quite sensitive to the phase and amplitude distortions which an adaptive array might produce. These distortions can be roughly divided into two classes: static and dynamic. Static effects are those which are inherent in the frequency-sensitive nature of an antenna array and which persist when the array weights are fixed. Dynamic effects are due to the adaptive nature of the array and the time varying (or noisy) spatial response it produces.

Dynamic effects are usually conjectured to be the more serious; the classical example is "weight noise" modulation of the phase and amplitude of a signal being nulled [BERNI, 1978; BRENNAN, et. al., 1977]. They are also the more elusive analytically, and are highly dependent on the particular implementation. It is the object of this paper to study the distortion produced by a static array antenna. In particular, we shall examine distortion of the output of a matched filter or signal correlator (i.e. of the signal's time autocorrelation function) when the signal is "filtered" by passage through an array antenna. We will ignore the practical aspects of dispersive or nonlinear elements, nonideal filters, etc., and will concentrate on the fundamental effects of an ideal linear array.

(A more complete analysis for both static and dynamic arrays is presented elsewhere [RASKA, 1978].)

2. ARRAY FILTERING EFFECTS

We consider the antenna array geometry shown in Figure 1. The arriving signal is assumed to be of the form

$$s(t) = A(t)\cos(2\pi f_0 t + \phi(t)) \quad (1)$$

where $A(t)$ and $\phi(t)$ are the amplitude and phase, respectively, of the rf carrier at frequency f_0 .

For simplicity, we introduce the complex envelope representation

$$s(t) = \text{Re}\{s(t)\exp[j2\pi f_0 t]\} \quad (2)$$

where

$$s(t) = A(t)\exp[j\phi(t)] \quad (3)$$

and $\text{Re}(\cdot)$ denotes the real part of the enclosed quantity. Since we are not considering dispersive effects of the array elements, the primary effect of the array is to introduce time delays and amplitude/phase changes between the signals at the various antenna elements. Using the definitions for the complex envelope, it is straight forward to demonstrate that when the signal is delayed by an amount t_i i.e. $s(t-t_i)$, it has a complex representation $s(t-t_i)\exp[-j2\pi f_0 t_i]$. If we further assume both amplitude and phase modulation can be introduced at each element the resulting N-element array output becomes (in complex form)

$$y(t) = \sum_{i=1}^N w_i(t)s(t-t_i)\exp[-j2\pi f_0 t_i] \quad (4)$$

where the $\{w_i(t)\}$ are the complex element weights and the $\{t_i\}$ are the differential time delays of the signal propagating across the array. Note from the geometry in Figure 1 that the time delays are very much dependent on the arrival angle of the signal, that is, we could be more explicit and write $\{t_i(\theta)\}$.

2.1 Matched Filter Output

Suppose the array output $y(t)$ is passed through a filter matched to $s(t)$. If the weights are static (independent of time), the resulting output is given by

$$r(\tau) = \sum_{i=1}^N w_i \exp[-j2\pi f_0 t_i] r_s(\tau-t_i) \quad (5)$$

where $r_s(\tau)$ is the time-autocorrelation function of the signal $s(t)$. Typically, autocorrelation pulses may be on the order of microseconds wide while propagation delays are on the order of nanoseconds; thus a common approximation is to write (5) as

$$r(\tau) \approx \left\{ \sum_{i=1}^N w_i \exp[-j2\pi f_0 t_i] \right\} r_s(\tau) \quad (6)$$

The reader will recognize the term in brackets as the "array factor" of the antenna at frequency f_0 [STEINBERG, 1976]. Equation (6) is commonly used to describe the array output whenever the incoming waveform is "narrowband". We will demonstrate that (6) is in general a poor approximation, especially if the signal is arriving in the vicinity of an antenna null.

2.2 The Array Filter Response

To show the desired filtering result, we start by obtaining the Fourier transform of (5),

$$Y(f) = \sum_{i=1}^N w_i \exp[-j2\pi(f_0 + f)t_i] S(f) \quad (7)$$

where $Y(f)$ and $S(f)$ are the Fourier transforms of $y(t)$ and $s(t)$, respectively. The matched filter output (in the frequency domain) then becomes

$$R(f) = |S(f)|^2 \left\{ \sum_{i=1}^N w_i \exp[-j2\pi(f + f_0)t_i(\theta)] \right\} \quad (8)$$

$$= |S(f)|^2 H(f, \theta) \quad (9)$$

In writing (8), we have again emphasized the delays are arrival-angle dependent. Equation (9) merely states that the static array can be viewed as an angle-dependent transfer function which relates the signal's power spectrum to the matched filter's output spectrum. The filter $H(f, \theta)$ is dependent only on array geometry (through the $\{t_i\}$) and the elements weights $\{w_i\}$; thus it has no relation to the incoming signal $s(t)$.

In order to interpret the results, we first expand $H(f, \theta)$ in a Taylor's series about $f = 0$ (recall we are using a complex baseband model to represent the signals),

$$H(f, \theta) = a(\theta) + (j2\pi f)b(\theta) + (j2\pi f)^2 c(\theta) + \dots \quad (10)$$

The matched filter output can now easily be interpreted using the derivative rule of Fourier transforms:

$$r(\tau) = a(\theta)r_s(\tau) + b(\theta)\dot{r}_s(\tau) + c(\theta)\ddot{r}_s(\tau) + \dots \quad (11)$$

where the overdots denote derivatives with respect to the variable τ . Equation (11) indicates that any signal distortion is dependent both on the array characteristics (through the complex coefficients $a(\theta)$, $b(\theta)$, ...) and on the signal waveform used (through $r_s(\tau)$, $\dot{r}_s(\tau)$, ...). Also, since the coefficients are complex numbers, the various terms in the sum are not generally in phase thus the array filter may operate differently on each of the signal quadrature components, resulting in both an apparent amplitude and phase modulation of the output correlation pulse.

We emphasize that our results in (11) is a quite general complex representation; it can be used to interpret communication performance of envelope as well as coherent detectors used at the matched filter output.

It is instructive to compare (11) to the commonly used approximation (6). The first term in (11) is exactly the same as the array factor in (6). Thus common approximations normally involve only the first term in the Taylors series expansion (11). This can be an especially poor approximation in the vicinity of a null where $a(\theta)$ is negligible but the other coefficients may not be. Such a case is illustrated in the examples to follow.

3. EQUALLY SPACED LINEAR ARRAY: SIMULATION RESULTS

As an indication of the type of results expected, suppose the array consists of N elements equally spaced d meters apart. This implies the time delays can be related to arrival angle through

$$t_i = (i-1) \frac{d}{c} \cos \theta, \quad i=1,2,\dots,N. \quad (12)$$

where c is the speed of light. Furthermore, suppose the beam is steered broadside so that all the $\{w_i\}$ are unity.

The transfer function $H(f,\theta)$ can now be expressed in closed form [STEINBERG, 1976],

$$H(f,\theta) = \exp\{+j(N-1)\frac{\pi d}{c}(f_0 + f)\cos(\theta)\} \left(\frac{\sin\left(\frac{N\pi}{c}(f + f_0)d \cos\theta\right)}{\sin\left(\frac{\pi}{c}(f + f_0)d \cos\theta\right)} \right) \quad (13)$$

On expanding $H(f,\theta)$, we obtain

$$H(f,\theta) = \exp\{+j(N-1)\frac{\pi d}{c}(f + f_0)\cos\theta\} \cdot \left\{ \frac{\sin\left(\frac{N\pi}{c}f_0 d \cos\theta\right)}{\sin\left(\frac{\pi d}{c}f_0 \cos\theta\right)} + \frac{\frac{\pi d \cos\theta}{c} f \left(N \sin\left(\frac{\pi d f_0 \cos\theta}{c}\right) \cos\left(\frac{N\pi f_0 d \cos\theta}{c}\right) - \sin\left(\frac{N\pi f_0 d \cos\theta}{c}\right) \cos\left(\frac{\pi f_0 d \cos\theta}{c}\right) \right)}{\sin\left(\frac{\pi d f_0 \cos\theta}{c}\right)^2} + \dots \right\} \quad (14)$$

Equation (14) merely illustrates how the coefficients in (11) can be obtained. We are unable to make further generalizations without assuming some typical parameters.

3.1 Array Filter Characteristics: Numerical Example

Consider a four element array with half-wavelength spacing at a center frequency f_0 of 350 MHz. Such a configuration would result in the antenna polar pattern shown in Figure 2. Note the antenna nulls occur at 0° , 90° , 120° and 180° in the upper hemisphere, as can be easily predicted from (13). The amplitude and phase of $H(f,\theta)$ are presented as functions of frequency for various arrival angles in Figure 3. From these plots we observe:

- (i) The phase is a linear function of frequency with its slope and intercept a function of arrival angle. (The discontinuity results at the origin to account for the sign change in $H(f,\theta)$ at the origin). Thus any nonlinear phase characteristics observed experimentally must be due to dispersive effects of the array components themselves.
- (ii) The magnitude can be represented as a constant plus linear term in frequency over a bandwidth of roughly 15% of the center frequency. (The constants depend strongly on the arrival angle).

- (iii) The first term of the Taylor series is adequate to represent the array at broadside while the linear term is strongly dominant in the vicinity of a null.

3.2 Output Signal Waveforms

In order to demonstrate the effects on signaling waveforms, we first assume $s(t)$ has a time autocorrelation function as shown in Figure 4. (This corresponds approximately to a PN phase-coded waveform with a chip width of 2 microseconds [DIXON, 1976].) In the following example, we show four possible waveforms for each arrival angle. The first, denoted as the "signal quadrature" component, corresponds to the matched filter output for a phase coherent receiver which is tracking the phase of the undistorted signal component. The second, denoted as the "derivative quadrature", corresponds to the output of a coherent receiver which is tracking the phase of the derivative component. For the numerical example presented, these signals are 90° out of phase; thus the label "quadrature" has been used to describe the two signals. The "envelope" plot is simply the output waveform observed with an envelope detector. Finally, we suppose a phase coherent detector is used where the reference phase is that of a signal arriving from broadside to the array; the resulting waveform is denoted as the "real axis" output.

Consider first the case when the signal is arriving at the antenna null of 0°. From equation (14), we observe that the undistorted signal component is identically zero, while the derivative term is nonzero. These results are confirmed by the plots shown in Figure 5, which shows that the dominate output waveform is due to the derivative of the signal autocorrelation. (The "grass" on the waveforms is due to the few number of samples used in the Fast Fourier Transform (FFT) computations). It is also interesting to note that the output (for all the cases examined) is nearly zero at the pulse center. Thus any communication system designed to sample the correlator output at the pulse center would perform extremely poorly. Of course, such a conclusion is almost automatic in the usual system analysis, since the signal is arriving in an antenna null. However, we do observe that an additional signal component (distortion) is present in the output and that component is very much dependent on the type of signal used (narrowband, broadband, etc.).

To illustrate the effects of arrival angle, we present the output waveforms for arrival angle of 5° in Figure 6. Here we see that both undistorted signal and derivative terms are present in the output. On comparing Figures 6a and 6b we conclude the signal quadrature is roughly a factor of 16 larger than the derivative quadrature. Thus it is obvious that the envelope, shown in Figure 6(c), should be dominated by the undistorted signal term. The "real axis" signal, shown in Figure 6(d), does still show the effect of both components in the output. Thus phase coherent detectors can exhibit a strong sensitivity to array distortion effects which may not be observed with an envelope detector. These distortion effects, depending on receiver design, can have a profound impact on overall communication performance. The next section presents experimental results which confirm such a conclusion.

4. EXPERIMENTAL RESULTS

The results presented in this section were obtained independently and predate the analysis by several years. The wideband signal was a 127 chip maximal length sequence clocked at 10 Mc/s and modulating a 40 MHz IF carrier. This signal was radiated and received broadside by a two-element adaptive array; the array was allowed to form nulls of various depths in the direction of the signal, whereupon its weights were frozen and data taken. The array output was processed by a spread-spectrum demodulator employing a 127 chip SAW device matched filter. The data detector was phase-coherent and employed a conventional phase-locked loop (PLL) (loop bandwidth of 1 KHz) to track the carrier phase in the matched-filter output pulses. The synchronization scheme employed an envelope detector which, because of the particular implementation chosen, required significantly greater signal to noise ratios than did the data detector. Typically, the data detector BER was less than 10^{-5} at the signal levels required to achieve synchronization.

The experimental setup was similar to Figure 1 except that the array had only 2 elements, the signal arrived broadside, and the "matched filter" was a somewhat more sophisticated modem. Interference consisted of thermal noise of the receiver.

In the first experiment, the modem input power level required to achieve synchronization was found as a function of null depth. This is shown in Table I, with 0 db corresponding to the level required of an undistorted (i.e., an un-nulled) signal.

TABLE I
MODEM PERFORMANCE vs NULL DEPTH

Null Depth (dB)	Relative Signal Level Required for Sync (dB)
0	0
3.1	1
8.5	4
11.8	6 (no data)
14.3	10.5 (no data)

For the shallow nulls, it was possible to compensate for array-induced distortion by increasing modem input power. This was not the case for nulls deeper than 10 dB. In these situations, the synchronization circuit could be made to function by applying sufficient power but no amount of input power could make the phase-coherent data detector yield a meaningful output. This was undoubtedly due to the PLL's inability to track the highly distorted phase of the RF structure within each correlation pulse. A photograph of the undistorted correlation pulse is shown in Figure 7a and is followed by photographs of the distorted pulses resulting from 11.8 and 14.3 dB antenna nulls. Although the phase distortion cannot be seen, the characteristic "derivative" type of pulse envelope distortion derived in (11) and illustrated in Figure 5c is clearly evident.

The transfer function of the adaptive array was experimentally obtained by using sinusoidal signals at 1 MHz increments and measuring the array output with a vector voltmeter. Figure 8 shows the results for array weights yielding 11.8 dB and 14.3 dB wideband nulls. Except for the phase anomaly occurring at 14.3 dB, they agree qualitatively with the analytically derived transfer functions of Figure 3. "Phase reversals" such as shown in Figure 8(d) are often observed experimentally. As was pointed out in the preceding section, they are not an inherent feature of array antennas but are probably due to phase-dispersive components of the hardware.

5. CONCLUSIONS

Both the analysis and the experimental data indicate that the distortion experienced by a wideband signal when it is nulled by an array antenna can be severe, even for moderate null depths. In the particular case where the signal is subsequently matched-filtered, the distorted filter output can be written as a weighted sum of the undistorted output and its derivatives. Coefficients in the sum depend on arrival angle and array weights; the derivative terms can be significant in a wide angle about the null, and dominate near the center of the null. For signals whose relative bandwidth is less than 10%, only the first derivative is significant.

The array phase-transfer function is linear, and the magnitude transfer function can be highly irregular and non-symmetric about the center frequency. Signal distortion is due entirely to the magnitude transfer function; the non-symmetry of this function can greatly distort the "phase" of a wideband signal and its matched-filter output.

When designing wideband systems which use phased-array antennas, especially adaptive arrays, it is extremely important to choose signal and detector structures which are robust to these effects. If there is a possibility that a desired signal can be nulled, then extreme caution should be exercised in employing phase-coherent detectors or even incoherent (envelope) detectors which rely on the shape of the matched-filter output envelope. It is considerably safer to use differential encoding schemes where the data resides in pulse-to-pulse characteristics, and/or detector structures which are insensitive to the shape of the correlation pulse.

As was discussed in the introduction, the results presented here are for a static antenna array. Another (and possibly more severe) set of problems is introduced when dynamics of the signal source and/or array weights are considered.

6. ACKNOWLEDGEMENT

The authors are indebted to Mr. John Graniero of the Rome Air Development Center for the experimental data presented herein.

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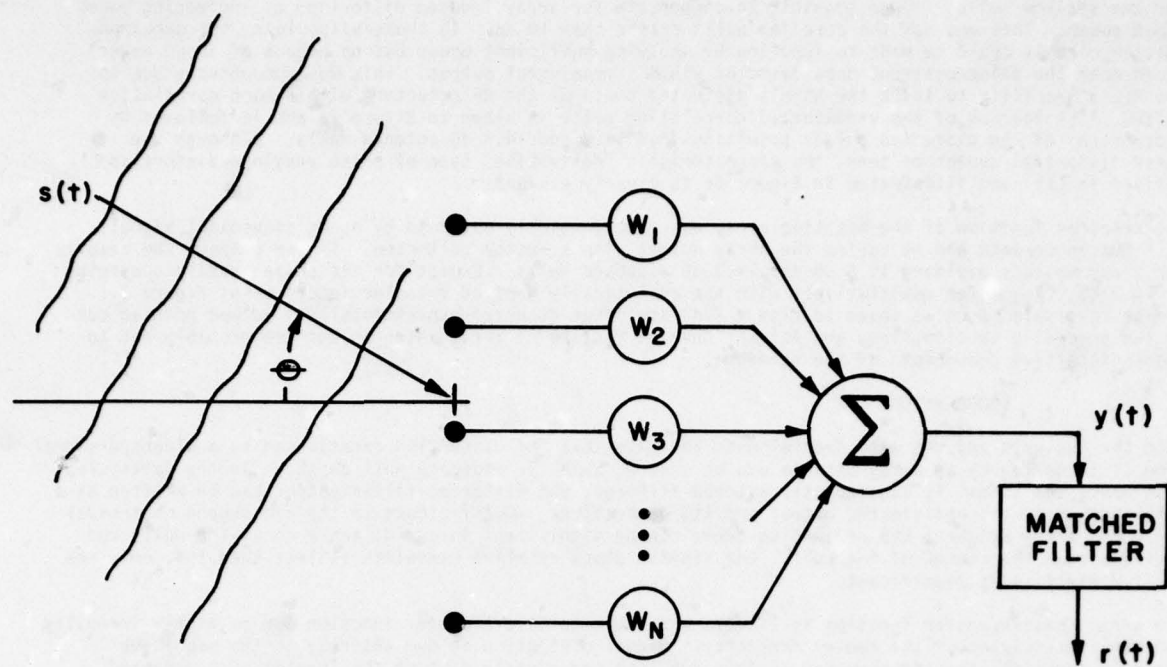


Fig.1 Array configuration

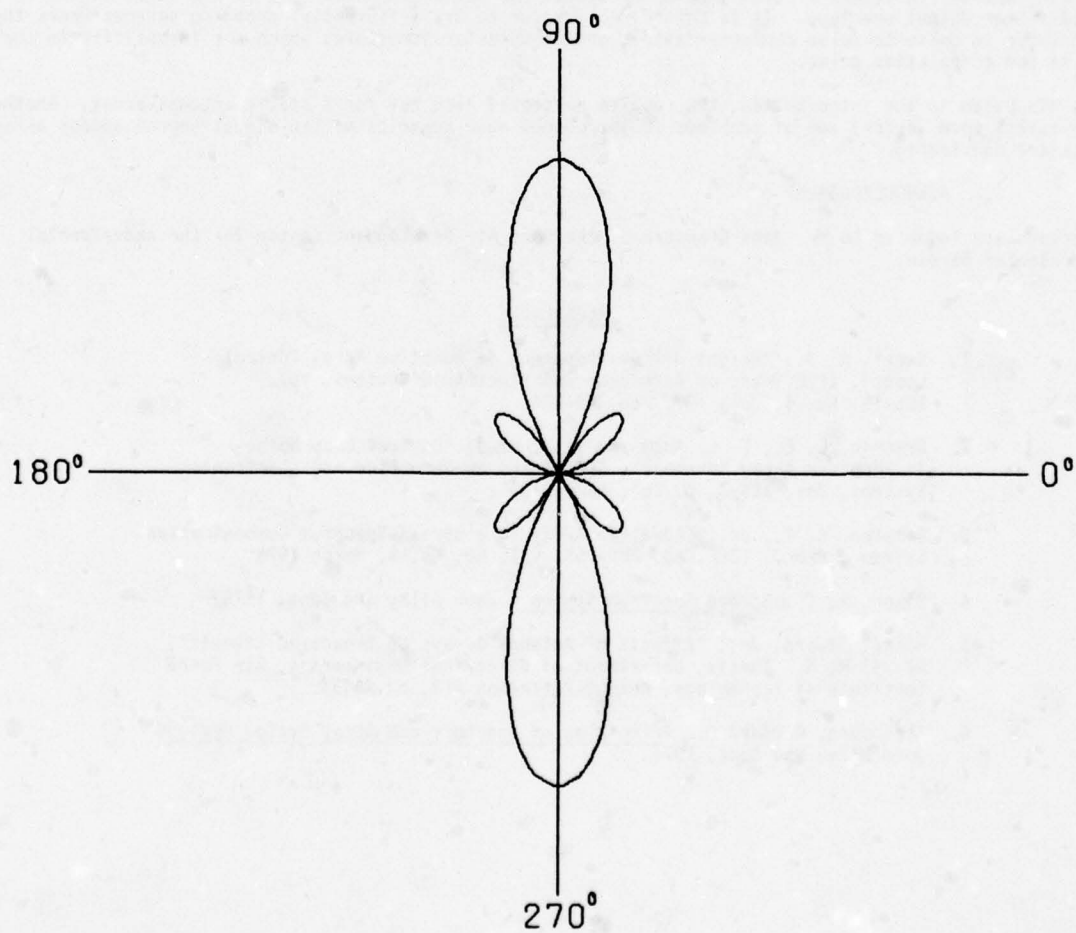
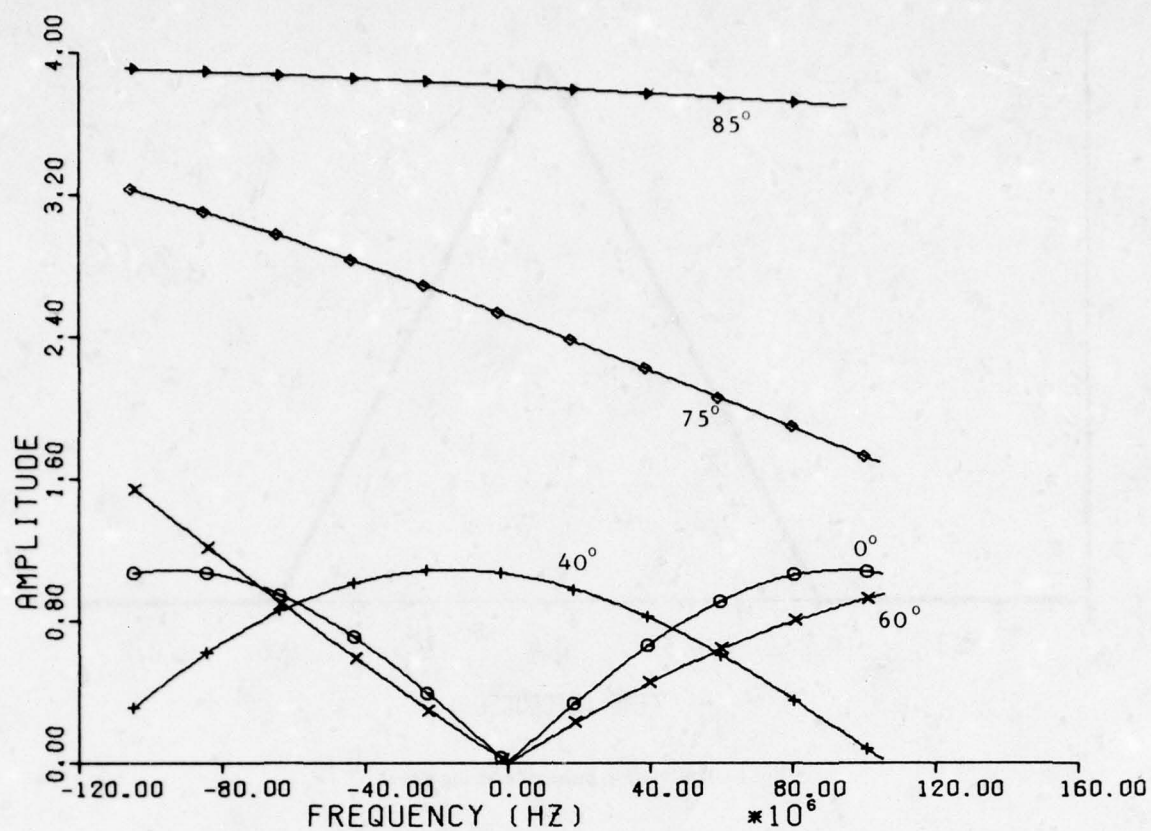
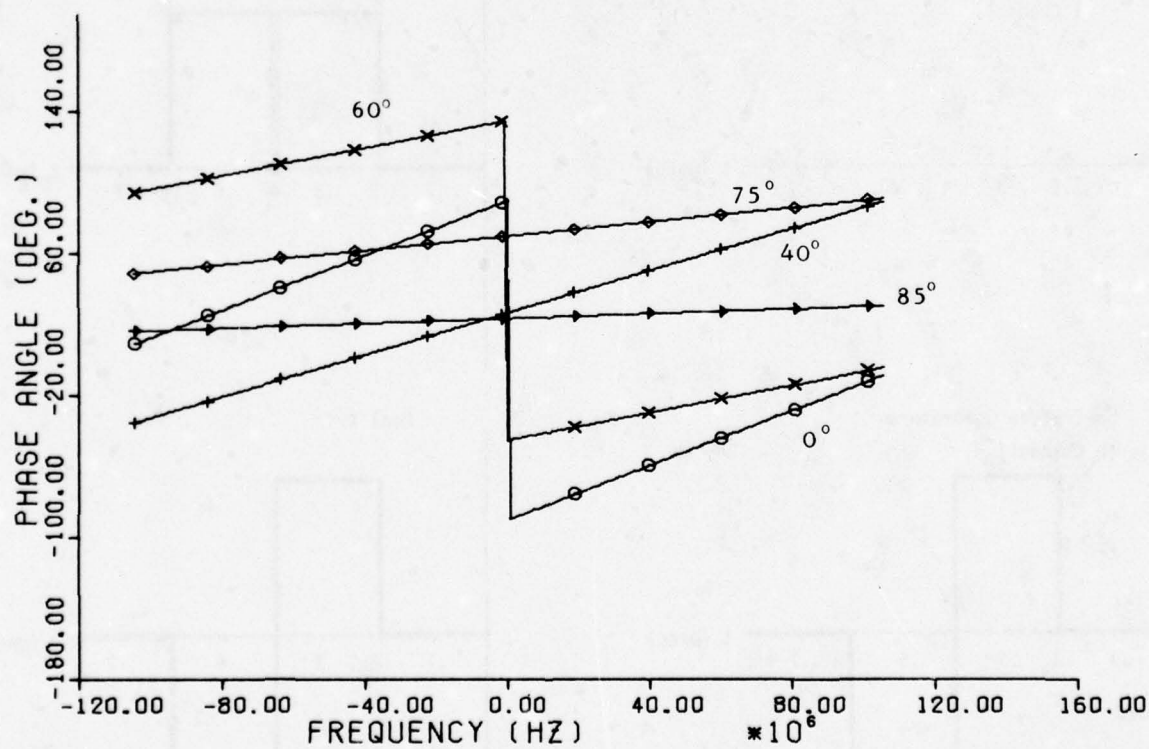


Fig.2 Polar pattern of four element array



(a) Magnitude response



(b) Phase response

Fig.3 Array transfer function

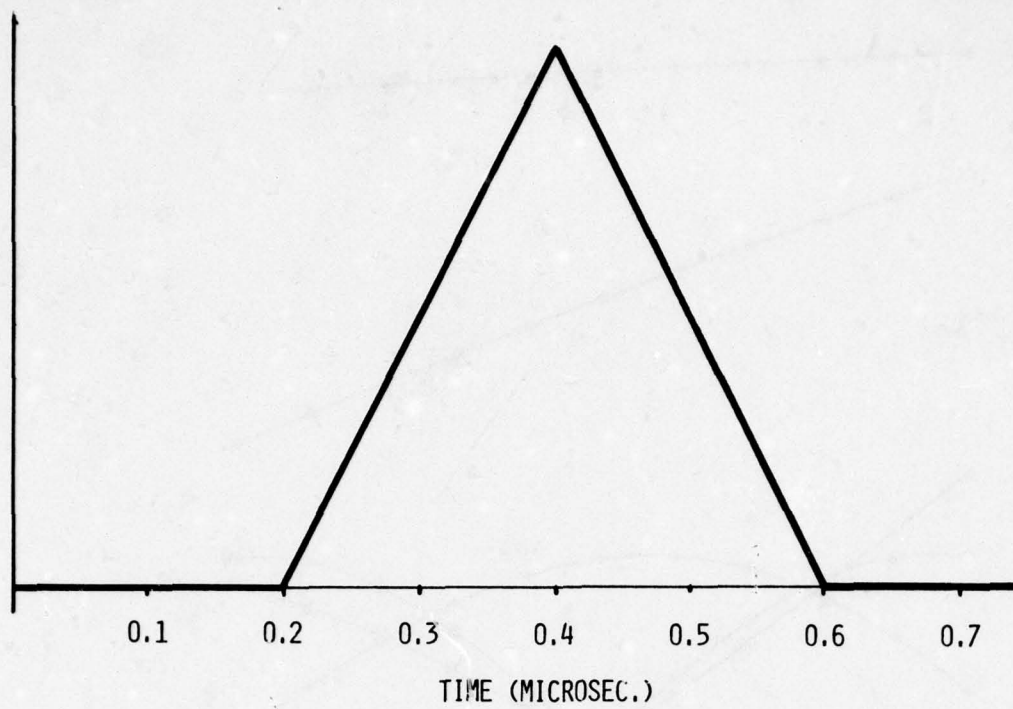


Fig.4 Correlation pulse of arriving signal

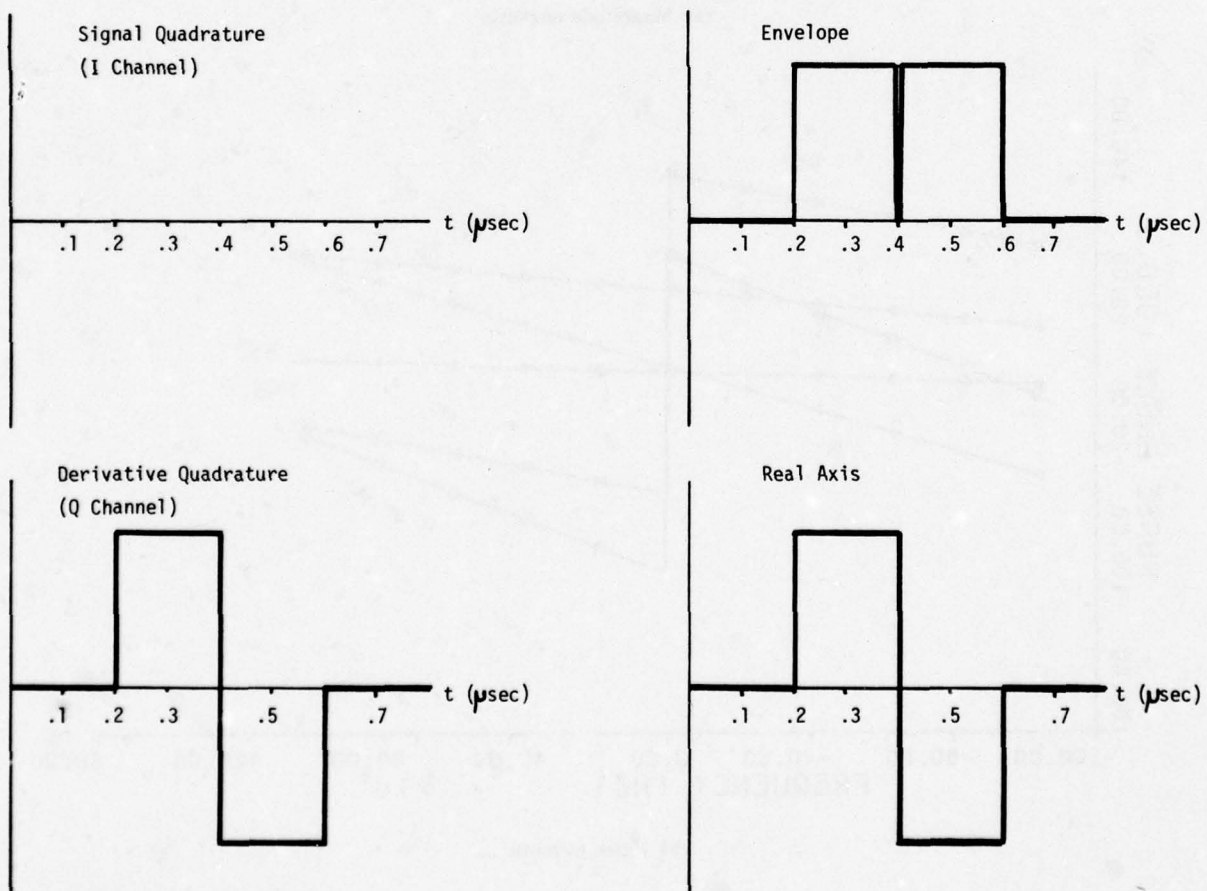


Fig.5 Calculated output correlation pulse for 0 degrees arrival angle

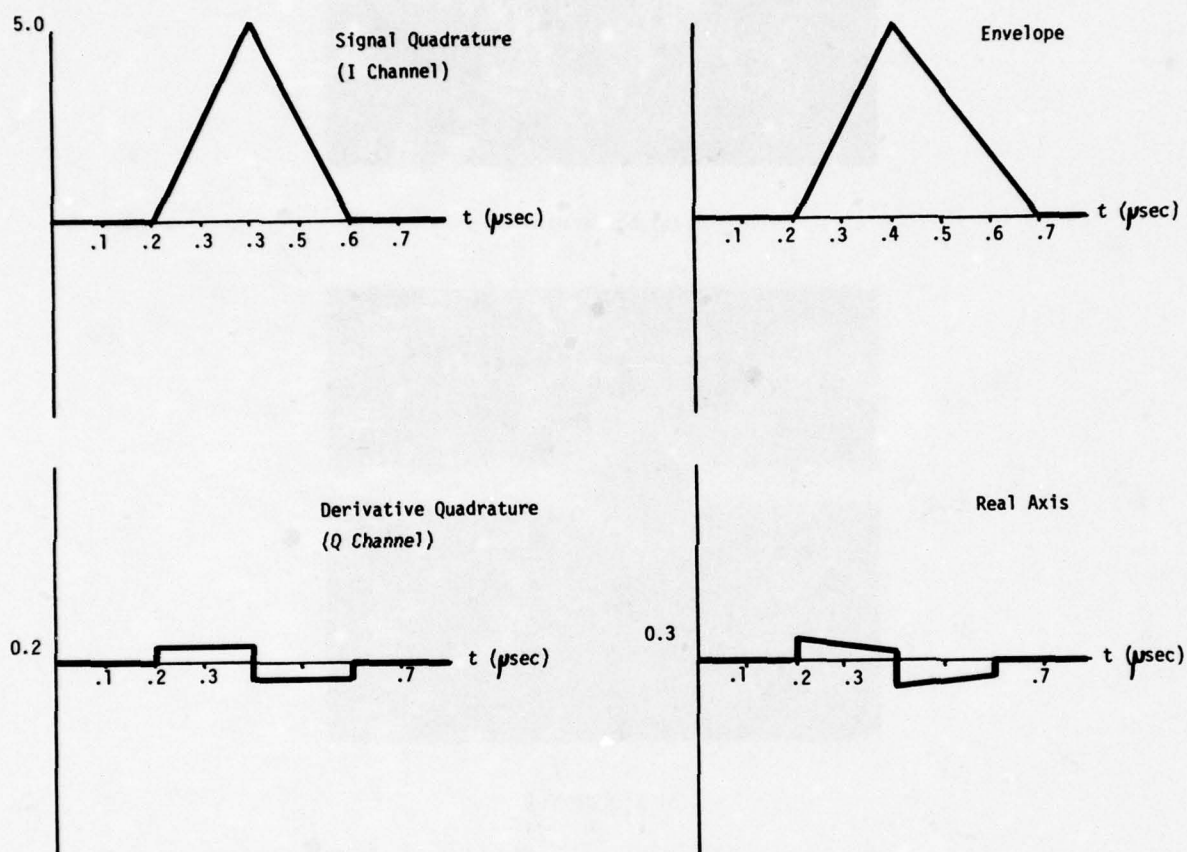
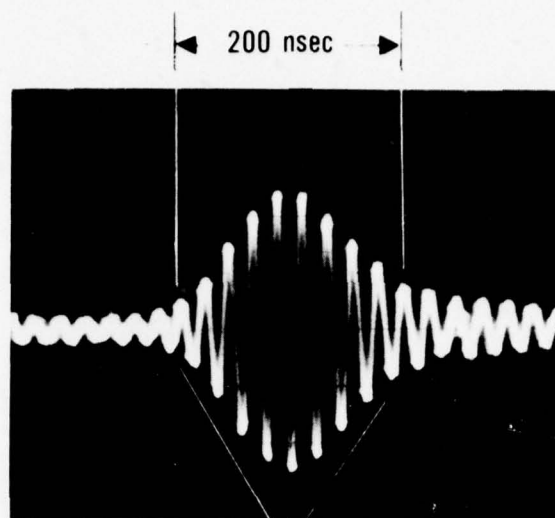
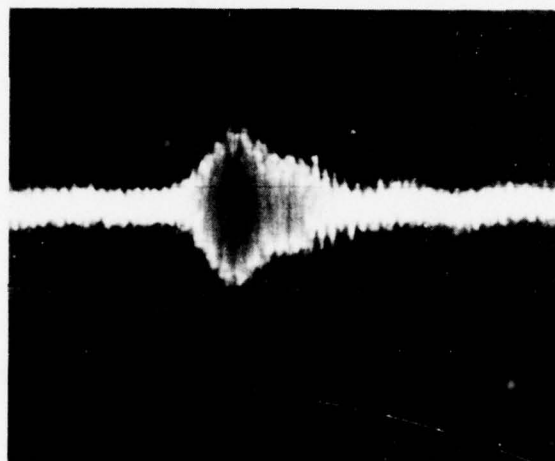


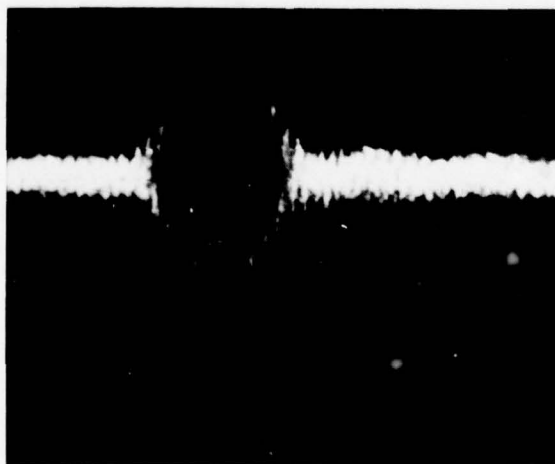
Fig.6 Calculated output correlation pulse for 5 degrees arrival angle



(a) Undistorted

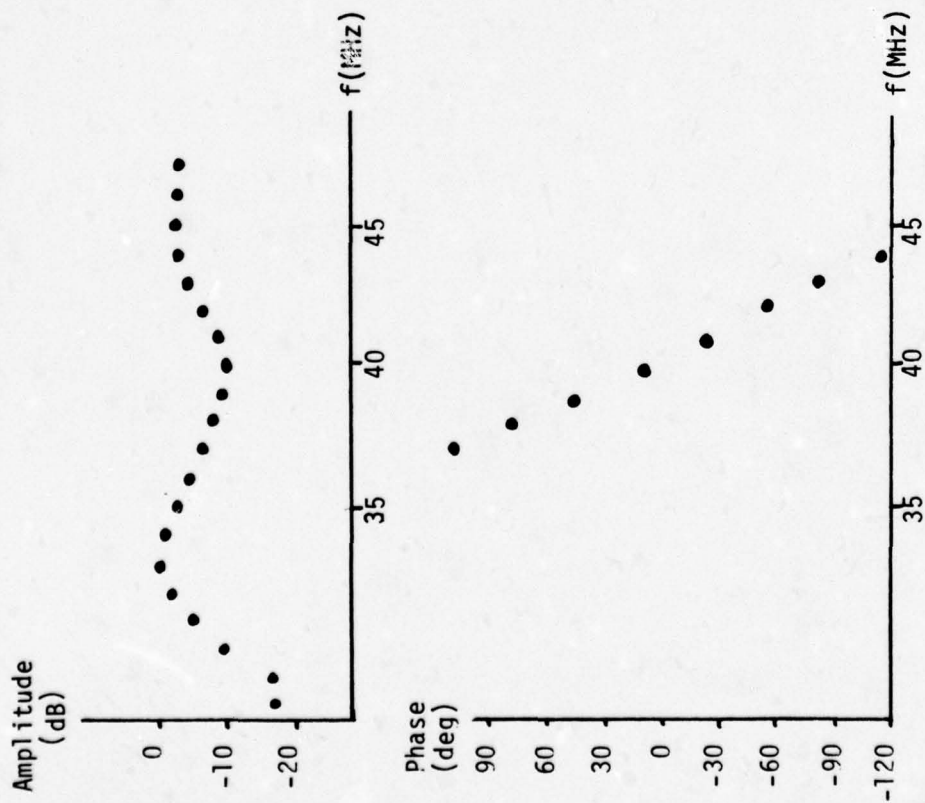


(b) 11.8 dB Null

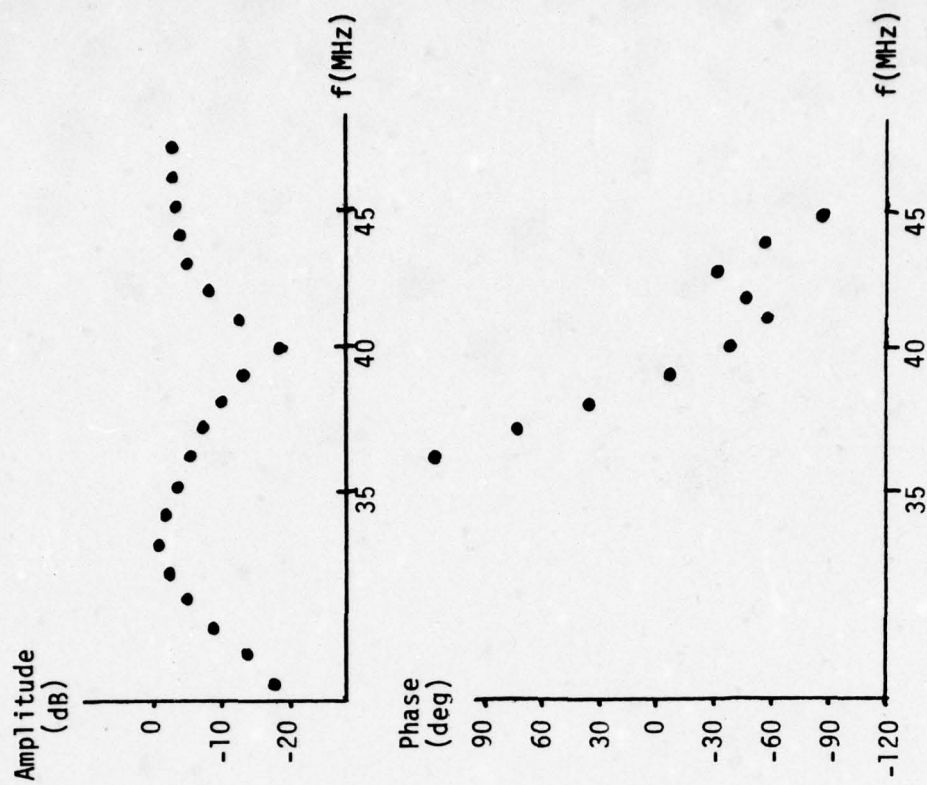


(c) 14.3 dB Null

Fig. 7 Measured matched filter output pulses



(a) 11.8 dB Nu11



(b) 14.3 dB Nu11

Fig.8 Array transfer functions

A DPCM CODING TECHNIQUE FOR THE TRANSMISSION OF VIDEO SIGNALS

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ABSTRACT

A method for the transmitting of digitally encoded video signals at reduced bit rates is discussed. Such methods are important in increasing the efficiency of a noise-resistant video link from airborne to ground stations. The algorithm used for bit rate reduction should be consistent with simple implementation and adequate picture quality, both under noise and noiseless channel conditions.

Described here is a DPCM coding algorithm that treats the information of the quantized differences as a sequence within the feedback loop. In the example discussed, a bit rate of 1.5 bits per picture element (pel) is provided with fixed-length words. Every other pel in the line is coded with a four-level and the remaining pels with a two-level quantizer. Therefore the information of every two adjacent pels is represented by $2 + 1 = 3$ bits corresponding to 1.5 bits per pel.

Two-dimensional prediction with three pels (adjusted to the coding scheme) and a line-to-line offset in use with two quantizers lead to an exchange of quantization and prediction errors that equalizes the varying accuracy of the quantization. At any given moment prediction and coding involve three pels with the 2-bit and one pel with the 1-bit accuracy.

The 2-bit quantizer is important for the rendition of edges and the 1-bit quantizer for the low visibility of channel errors. By turning over to two equal quantizers the bit rate can easily be changed to 2 or 1 bits per pel.

The efficiency at the rate of 1 bit per pel can be increased by coding the central (or target) area with a higher accuracy than the rest of the picture.

For example each area has the same number of pels with the accuracies of 1.5 and of 0.5 bits per pel. The 1.5-bit DPCM is applied to the pels in the centre and a 2-bit DPCM to the average of four pels outside.

Performance results are presented and compared with the results for hybrid transform/DPCM coding, operating under the same conditions.

BUDOS - A MULTIPLEX DATA BUS TRANSMISSION SYSTEM

S Øderud

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SUMMARY

Today's weapon platforms have been large and complex. NATO's recognition of this and a desire to simplify the method of interconnecting all the user interfaces located throughout the platform led to the appointment of a NATO group with the task to write standard interface specifications for naval digital equipment.

The highway or serial data bus format is appropriate to systems where data sources and users are distributed. One interface specification STANAG 4156 and one data transmission system BUDOS under development at A/S Kongsberg Våpenfabrikk will fulfill the requirement of STANAG 4156.

The polling/contention type format used for this new system will give system advantages and the use of more than one bus data channel will give system redundancy and gradual degradation. The new data distribution system BUDOS will go onboard coast guard vessels under construction in NORWAY and will be used for ordinary point-to-point addressed data and broadcast transmission.

1. BACKGROUND AND SYSTEM PHILOSOPHY FOR STANAG 4156

Normal System growth of diverse equipment without excessive rewiring and life time refit on the weapon platform has led to the recognition in NATO for standard interfaces to serial digital multiplex data bus for network systems. The existing specification MIL-STD-1553A (Aircraft Internal Time Division Command/Response Multiplex Data Bus) and the new STANAG 4156 (Standard Specification for a Asynchronous Input/Output Interface for Multiplex Terminals on ship board General Purpose Data Bus Systems) are two of these standards.

The work in organizing STANAG 4156 started back in December 1973 when NIAG (Nato Industrial Advisory Group) Sub-group 6 was formed with the task to write standards for the interface to naval digital handling equipment. Over the last two years NIAG has prepared two digital interface standards STANAG 4153 for High speed computer like point to point interfaces and STANAG 4156 for interface to network systems. The group early recognized there were two modes of philosophies likely to be involved in shipborn systems, utilizing point to point links and highway or bus connections. At an early stage it was realized that a single interface should not be optimized for these two modes.

In this paper I will concentrate on the interface specification optimized for Network Interface STANAG 4156 and one bus system application.

1.1 Interface Location

The NIAG Sub-group 6 started out trying to define a complete bus or network system. However, divergent requirements from relevant navies regarding system complexity, levels of capacity, redundancy, and different grades of flexibility, led to the conclusion that the group should concentrate on the "interface" to a network system. Only the minimum requirements for the network system are to be specified, and the interface should be simple as possible, also small users must without too much complexity build their interface to satisfy the standard.

See Figure 1 INTERFACE LOCATION.

The group also recommended that an input part should be independent of an output part, forming one total data channel. Two users that employ the same interface may be directly interconnected in the absence of a network by means of a simple coupling device.

1.2 Interface Alternatives

Within the network each message is headed with a 16 bit control word. The control word will comprise of information concerning message word identification, physical address, and a message number. This information is necessary in most systems to address and identify the subsequent data.

It has also been the purpose of the standard to serve very simple users. The control word can in this case be added to the data in the terminal for an input channel and stripped off in the output channel (TYPE A PROTOCOL). The network system must for such messages have a prior notice of the address information.

More generally preferable for intelligent devices such as computers, the control word will be sent directly to the users device, and it is the user devices responsibility to decode the control word and to respond as requested (TYPE B PROTOCOL).

See Figure 2 INFORMATION MESSAGE.

1.3 Electrical Interface

The NIAG Sub-group 6 felt that an electrical interface must be made of readily available components and the specified electrical interface must be made according to international recognized specifications. The CCITT recommendation V.11 is therefor specified.

1.4 Bus System

The STANAG 4156 defines the functional and electrical characteristics of a network synchronous input/output interface for use in systems which are to be interconnected via a shipboard data network system. The information transfer protocol is defined and the requirements which the protocol and interface characteristics impose on the multiplex bus and users system are established. Recommendations are made concerning the physical characteristics of the interface relating to cables and connectors.

The network must be transparent to the data submitted from the different users, and no data must be stopped or ignored due to deficient parity or other errors. The network systems shall not "store and forward" data on a message basis, and a propagation time of 50 μ sec. shall not be exceeded. The network shall provide for both source and sink initiation of messages and both periodic and aperiodic transfer. The bus system shall transfer messages with a maximum length of 512 datawords consisting of 17 bits. All bus systems shall be capable of transferring single address data on a point-to-point bilateral basis. Bus systems that optionally provide unilateral transfer capability shall be able to transfer source initiated messages, broadcast, via a single step process to any addressed sink or specified groups of sinks.

The response time is defined as the delay between the initial request for message transfer and the arrival of the first bit of the message at the intended output interface. The response time for most bus systems is variable and dependent on user systems connected, capacity and traffic load. It is the system designers responsibility to simulate or otherwise ensure that the maximum and nominal response times are kept within acceptable limits. As a guideline a normal system will for a 50% probability have a response time of approximate 200 μ sec, increasing to 1 m. sec. at a 99% probability.

2. BUDOS PRINCIPLE SYSTEM LAYOUT

A/S Kongsberg Våpenfabrikk have under development a Multiplex Data Bus Transmission System fulfilling the requirements of STANAG 4156 called BUDOS. Its purpose is to replace the conventional point-to-point wiring between shipbourne electronic equipment. In BUDOS information between the users is transmitted on common multiplex bus cables which substantially reduces the number of interconnections and cabling costs. Compared with traditional point-to-point wiring BUDOS offers the designer a tool to make a distributed and modular system. Using a system as BUDOS for your communication, independent system programming can take place in the individual units or between groups of units. BUDOS also offers the system designers one focal integration point to the individual users facilitating simplified unit test. BUDOS is designed to meet requirements of the STANAG 4156, and all future equipment following this standard can be easily interfaced.

2.1 The Data Bus

Figure 3 shows the principle system layout of BUDOS. The Data Bus consisting of one or more coaxial cables are running through the ship. Each cable comprises one or more frequency multiplex channels, thus allowing a number of simultaneous connections between subsystems. Each channel has a 3 Mbit data rate. The digital data transmitted from the users is divided into channels using a frequency division multiplex system. The channel frequencies are from 30 MHz upwards in 10 MHz steps.

2.2 Interfacing Subsystems to BUDOS

The users are interfaced to the data bus by means of a multiplex terminal (MUX terminals). The MUX terminals are so designed that a user has access to every bus cable and every channel on each cable. Further the MUX terminal can handle as many simultaneous connections as there are channels on the bus. The user interface is a half duplex interface, therefore the user can not transmit and receive simultaneously. Two users connected to the same MUX terminal can also communicate, however, this connection is not a short cut within the MUX terminals, but will use the main bus channel, just like any other connection between users connected to the different MUX terminals.

The two different interface protocol described in the STANAG 4156 can be utilized with the BUDOS-system. The type A protocol option (DATA ONLY), data will only be exchanged with the user, and the bus system will internally provide the addressing capability. Where type B protocol option (control and data) is used, the user can internally address all other users connected to the bus system, and the sub system is able to exchange various types of data messages with all the other users.

2.3 System Capacity and Bit Rate

The maximum BUDOS installation allows 15 MUX terminals with up to 8 user interfaces. BUDOS is designed to handle a bit rate of 3 M bit per sec. The bit rate on the main channel is identical to the bit rate at the user interface. Other bit rates can be accomplished, but this will require minor changes in the MUX terminal hardware. With a maximum of 4 data channels a total of 12 M bit of data can be handled with the BUDOS system.

2.4 Data Bus Control

Each separate data channel is controlled by a channel controller. The task of these controllers is to offer channel access to the users. In periods when the channel is not occupied, the channel controller asks each connected multiplex terminal one at a time, if one of its associated user requires a channel, if so, the multiplex terminal starts to transmit on the channel. The channel controller does not command a multiplex terminal to use a specific data channel, it merely offers the channel for use.

The polling is performed by transmitting a special "poll" control word addressed to the desired multiplex terminal. Because polling is performed when the data channel is not occupied no separate control line exists on the data bus.

All channel controllers operate entirely independent of each other, and can be located in different multiplex terminals. An error in one channel controller will only reduce the system capacity by one channel.

The channel controller has no knowledge of the information being transferred, is ignorant concerning message number, sink or source addressing etc. All the channel controller has to know is the number of multiplex terminals implemented, in order to offer the idle data channels to them.

The priority of the multiplex terminals is determined by the polling sequence of the channel controller. High priority multiplex terminals are simply polled more often than lower priority ones.

3. PROTOCOLS AND DATA EXCHANGE

All data exchanged is based on messages consisting of 17 bit (16 bit + parity) words. The maximum message length is limited to 511 data words + the control word.

All messages consist of a single control word or a control word followed by one or more data words. The control word contains message protocol information together with user and multiplex address information.

As previously mentioned two different types of users may be connected to BUDOS, type A with simplified protocol or type B with complete protocol. If the user is a type A system, the control words are provided by the bus system at transmission and removed at the multiplex terminal at receipt of a message. The type B user is itself responsible for providing necessary control words. The type A and B users use the same electrical interface to BUDOS.

3.1 Word Format

A data word consists of 17 bits (16 data + 1 parity bit). The least significant bit is transferred first, the parity bit last. See Figure 4, Data word layout. Data words are not decoded by the bus system.

3.2 Control Words

Figure 5. shows the layout of the control word. The general layout of the control word is in accordance with STANAG 4156.

A. Multiplex address.

The address of a multiplex terminal is specified with 5 bits. Each multiplex terminal has its own address. The address 00000 is reserved for broadcast use in accordance with STANAG 4156. A total of 31 multiplex terminals may be addressed.

B. User Address field.

The address of the user system is specified with 3 bits. This address specifies 1 out of 8 users connected to the multiplex terminal.

C. Message number field.

This field with 6 bits contains a number specific for the receiving user in order to identify the message.

This field is not decoded by the bus system, and has no influence on its operation.

D. WI-word identification bit.

This 2 bit field provides identification of the control word function.

RR - Receive Request control word. (10)

The user that will transmit this control word requests to receive a data message indicated by the message number from the user specified in the address field.

TR - Transmit Request: (11)

The user that transmits this control word requests to transmit a data message indicated by the message number to the addressed user.

DM - Data Message (00)

If the Data Message is transmitted in response to Receive Request control word (RR) the Data Message control word (DM) indicates that the sequenced data word comprised a Data Message identified by message number transmitted from the user identified by the address field.

If the data message is sent as unilateral transfer data, the Data Message control word (DM) indicates that the message identified by the message number, is transmitted to the user identified by the address field.

If the data message is a broadcast message the data message control word indicates that the subsequent data word comprises a broadcast data message. This is indicated in the first part of the address field.

E. A single odd parity bit.

The parity bit is not set, removed, or tested by the bus system.

3.3 Broadcast Control Word

In addition to the ordinary point-to-point addressing, BUDOS includes a broadcast capability. This means that data messages may be transmitted to several users simultaneously. Figure 6. The broadcast control word gives information concerning the different bits.

- A. The MUX multiplex address part contains (00000) to indicate a broadcast data message. This address is decoded by all MUX terminals, and further processed by all MUX multiplex terminals, programmed to receive a broadcast message.

- B. The broadcast address.

This is a subaddress decoded by all multiplex terminals that are programmed to receive broadcast messages. The multiplex terminals can with this address forward the message to a group of connected users. 8 different groups can be selected from this 3 bit address field, and each group may consist of 0 to 8 users.

- C. Message number field.

This field contains numbers specific to the receiving user for message identification.

- D. WI - word identification bit.

The WI bit (00) indicates data message control word.

3.4 Message Exchange Protocol

There are 4 different message exchange protocol that may be used in BUDOS. See Figure 7.

- Unilateral source indicated point-to-point transfer.
- Sink (receiver) indicated point-to-point transfer.
- Bilateral source indicated point-to-point transfer. A mode where the message transfer is mutually agreed upon by source and sink.
- Source indicated broadcast transfer.

3.4.1 Unilateral Source Initiated Point-to-point Transfer.

When a source user is ready to transmit data, the source transmits a data control word plus data to the sink user through the bus system. All the timing and proper bus controlling will be handled by the bus system. The address field in the data message control word is the address of the receiver. It must be noted that this is a unilateral transfer, and if the addressed user is busy when the data arrives the data message will be lost. This is one step data transfer and is normally used only for periodic data or when the source is notified through another message from the addressed user if the message is correctly received and understood.

3.4.2 Sink Initiated Point-to-point Transfer.

The sink initiates the transfer by sending a Receiver Request control word, (RR) that is addressed to the source system. The source user responds with the requested message which is preceded by a Data Message Control word (DM), carrying the source address.

Due to the fact that BUDOS is a half duplex access system, no control word address for bus addressing is required from the user answering an "RR" message. The answering user of the "RR" uses the same bus access when sending the requested data thus eliminating the need for calling the RR originator on a separate addressed bus access as would be the case in a simplex system.

This two step transfer mode is highly efficient and should be used wherever possible.

In response to Receiver Request the source will transmit a data message control word and data, back to the sink. This connection will be closed if no Data Message is transmitted within 50 μ sec. after receipt of the Receive Request word (RR).

Typical application for sink initiated transfer are as follows:

- The sink user is requesting data from a simple user.
- Two or more sink users are requesting data independently from the same source (sensor). The source not interested in the identity of each of the sinks, merely loads data into registers which can be read out in response to Receive Request from any number of sinks.
- The source is a bus orientated processor system and the sink user can, in specific main memory cells read data, addressed with the message number. The source device will not be loaded with this data handling.

3.4.3 Bilateral Source Initiated Point-to-point Transfer.

The source initiates transfer by sending a Transmit Request control word (TR) that is addressed to the sink user. The sink user if not busy will respond with the Receive Request.

The sink user must respond within 50 μ sec. If there is no response, the source user must send a Transmit Request again at a later time.

When the source user receives Receiver Request it should respond by transmitting the Data Message header word (DM) followed by the data.

Note that the Data Message address field always carries the sink address.

As for sink initiated point-to-point transfer the time between the receipt of Receive Request and the transmission of Data Message control word (DM) back to the sink a maximum time of 50 μ sec. is allowed.

This is a 3 step source initiated sequence, and should only be used when the preferred sink initiated mode can not be used.

Typical cases for source initiated transfers are the following:

- The source user is transferring data to sink device that does not have the capability to initiate the transfer.
- The message is valid at discrete times known only to the source device.
- The message is transferred infrequently but requires timely transfer thereby ruling out the possibility of low rate periodic requests from the sink.
- The message is being sent to a new or unusual sink device and the new sink device does not know that it should request the message. This will be the case in back-up mode or when operational mode changes take place.

3.4.4 Retransmission.

There is no automatic retransmission capability built into the bus system. User systems that do not receive data messages from another user upon request, are responsible to retransmit the request themselves. Because too many retransmissions will load the system the following transmission procedure is recommended: Users should request a message no more than 4 times at the minimum time interval. Subsequent attempts to request a message from an unresponsive user should typically be at a rate of one request per second.

4. REDUNDANCY AND GRADUAL DEGRADATION

BUDOS has been designed so that all failures shall result in gradual degradation rather than a full loss of the entire communication information transfer system. This was also the case in most systems before with dedicated wires and point-to-point connection. It is vital that this gradual degradation is also achieved with the new data network. If considered a prime controller and a back up controller the system runs normally until the prime controller fails. The back up controller then takes over and runs the system at the same capacity level. If the back up controller fails, the system totally fails. During normal operation you have a back up controller that only gives you extra electronics and adds nothing to the system, idle redundancy. In BUDOS the channel controller, one for each channel, is distributed in the system. By adding more channels you are adding more channel controllers.

There is a trade off between a level of redundancy and level of total capacity. With 4 channel controllers and a sudden failure in one of the controllers the system capacity will be reduced with 25%. With a loss of 3 channel controllers you will still have a capacity of 25%. No messages will be dropped out, but the system response time will increase. Increase in response time should be taken care of in the users sub system and if programmed correctly should reduce the update rate for the low priority messages. If at a later time in a vessels life cycle new sensors and new systems are introduced or the data load increases more channels can be added without any implementation or modifications to the existing users systems.

In the same way as loss of channels will give reduced capacity, loss of bus cables will also, if the system is equipped with more than one bus cable.

5. MAINTENANCE

Previously in this paper it was shown how the channels are offered to the different multiplex terminals through the polling technique. Any user that has information to be transmitted can when offered an idle channel from the multiplex terminal use that channel. The user has no knowledge of which channel he is using. He will only use the first one which becomes idle. If there is a break down in one or more of the channels this will not be known to any of the users if they are not given the opportunity to chose a specific channel, and check the channels out one by one.

Going back to an earlier statement concluding that a traffic controller does not command a user to take a specific channel but only offers the user that channel, we can expand this fact. If a user is given the opportunity to see which channel he is offered or only recognizes offers from specific channels we can then check out all the different channels and connections in the BUDOS system.

At each multiplex terminal there is one "special" user interface with one extra interface line. This difference gives a multiplex system user the capability of only recognizing offers from one programmed channel. The user normally a computer can act as a maintenance unit together with this normal function, connected to this specific user input with this extra interface line. The maintenance computer can request status messages via Receive Request calls from all the other different users on all the different channels. This test will detect errors in the multiplex terminal modules, in the cables, and in the user interfaces. Since every multiplex terminal has this special input, which can also act as a standard user interface to the BUDOS system, the maintenance function can also be distributed and is not hung up by single point failure in one maintenance unit. It is a standard interface that is used for maintenance function and one of the connecting computers can be used to utilize this function for very little extra cost.

The previously discussed maintenance checking is performed on-line. During system tests and in the pre-installation phase another unit can be connected to the BUDOS system for supervision of the total message flow in BUDOS.

Together with normal fault detection the purpose of this unit is to calculate traffic statistics worst case delays, and message utilization.

6. PRACTICAL IMPLEMENTATION OF BUDOS IN THE RNON'S COAST GUARD

A new type of coast guard vessel is under construction in Norway.

The first three vessels to be built will be of frigate size (2800 tons). The total electronic package to go onboard will be about 150 units, and for the data interchange between the major units BUDOS system has been selected in the pre-study phase.

The Navigation and Command Control and Information System NAVKIS which is planned to go onboard these vessels will be connected to the data bus system BUDOS, as simplified in Figure 8. Data Bus System for NAVKIS.

As seen from Figure 8 there will be three MUX terminals, and a total of 2 cables used. To reduce the single point failure all units which are not duplicated by other sensors are connected to two multiplex terminals. A total failure in any MUX terminal will therefore not extensively reduce the operation of

the system. Most of the processors used in the NAVKIS system will use A/S Kongsberg VÅpenfabrikk's new data processing system, KS-500, which is a bus oriented processing system. The interface module to the BUDOS system will be an active module and will collect and store information directly in the KS-500 main memory, and will not interrupt the processors operational programme during this function.

Since not all units are delivered with interface according to STANAG 4156, also in the NAVKIS system, interfaces as synchro type and 20 mA current loop will be used. These interfaces will be premultiplexed and converted to a format according to STANAG 4156 before being introduced to the BUDOS system. This pre-multiplexing will not take place in the standard BUDOS terminal, but in remote units or in sensor cabinets.

It is also to be noticed that the power has to be distributed in the same way as the data and interfaces are distributed. In the NAVKIS system power will be individually controlled and supplied to each of the 3 multiplex units.

The total data load for NAVKIS system will in the initial phase be approximately 2 M bit. The load during reprogramming is not taken into consideration in these figures. The total 4 channel utilization will be approximately 2%. With only one channel in operation the utilization will increase to approximately 8%. The response time with 50% probability with 1 channel will be approximately 35-40 μ sec. and with 99.9% utilization approximately 5.5 msec.

With BUDOS data transmission system the NAVKIS project will have an attractive data communication system for the future.

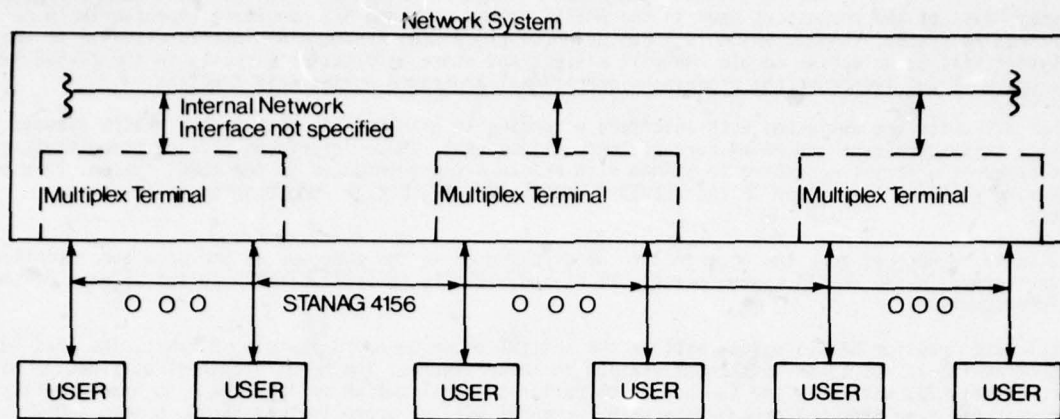


Fig.1 Interface location

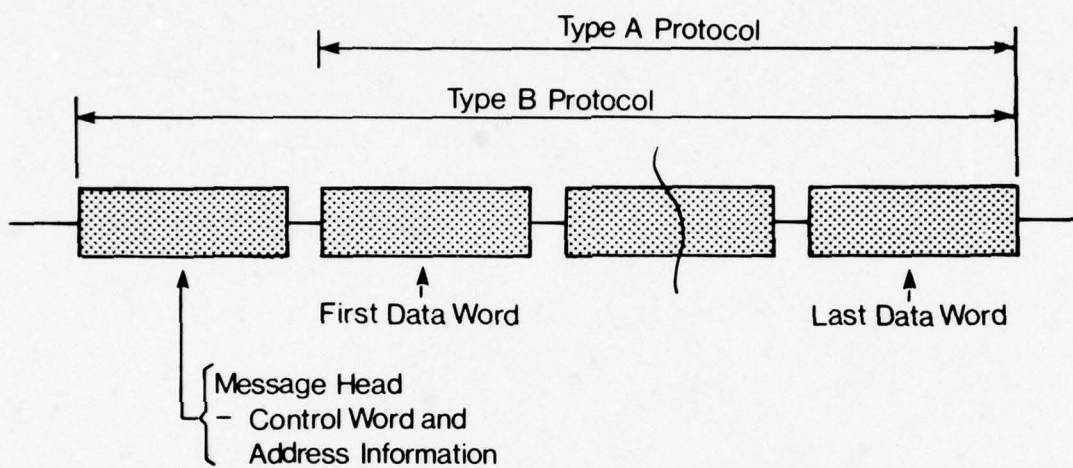


Fig.2 Information message

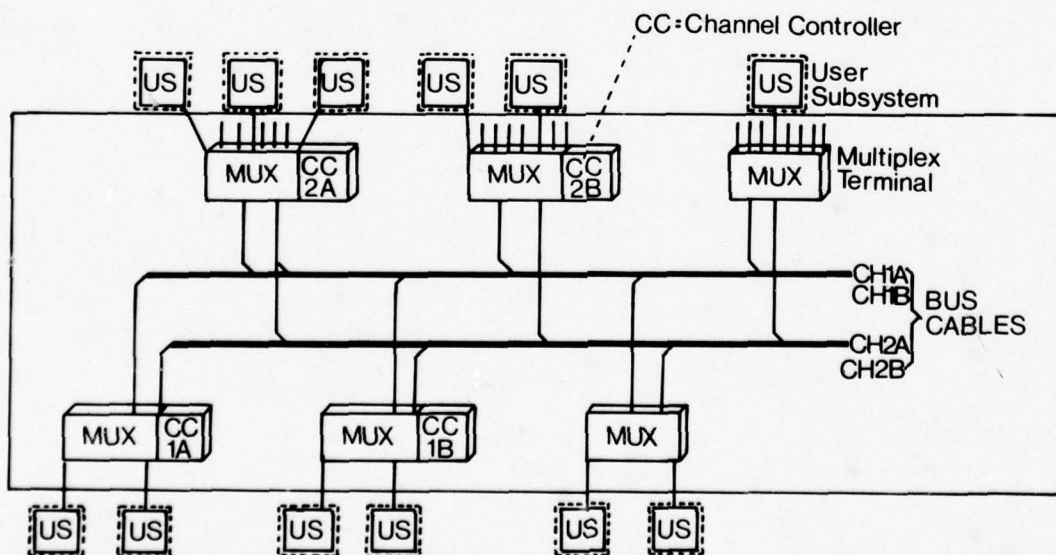


Fig.3 BUDOS principal system layout

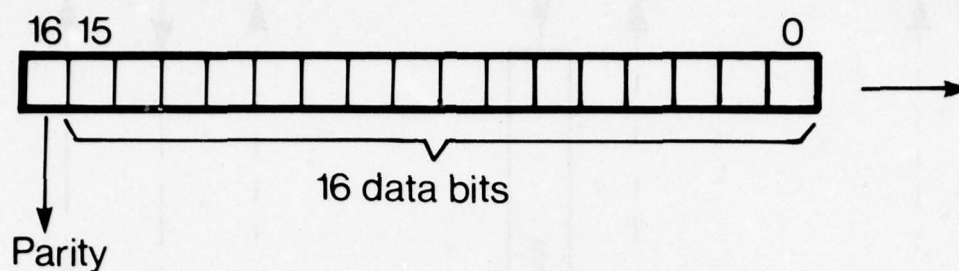


Fig.4 Data word layout

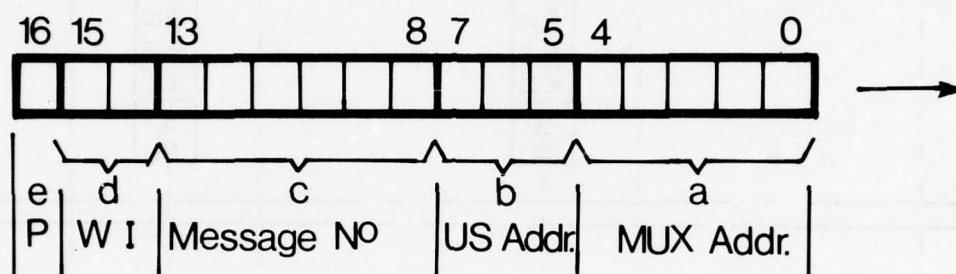


Fig.5 Control word layout

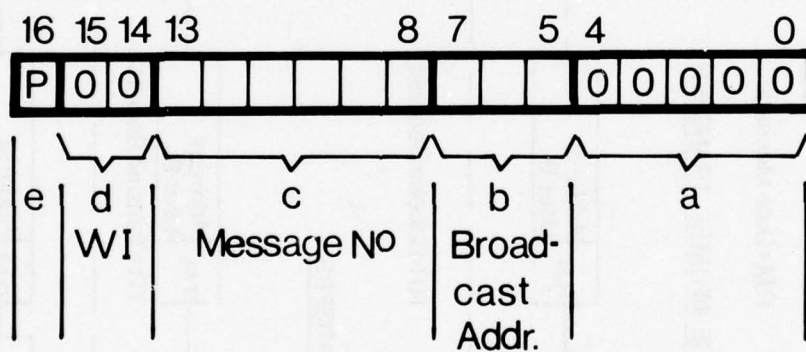


Fig.6 The broadcast control word

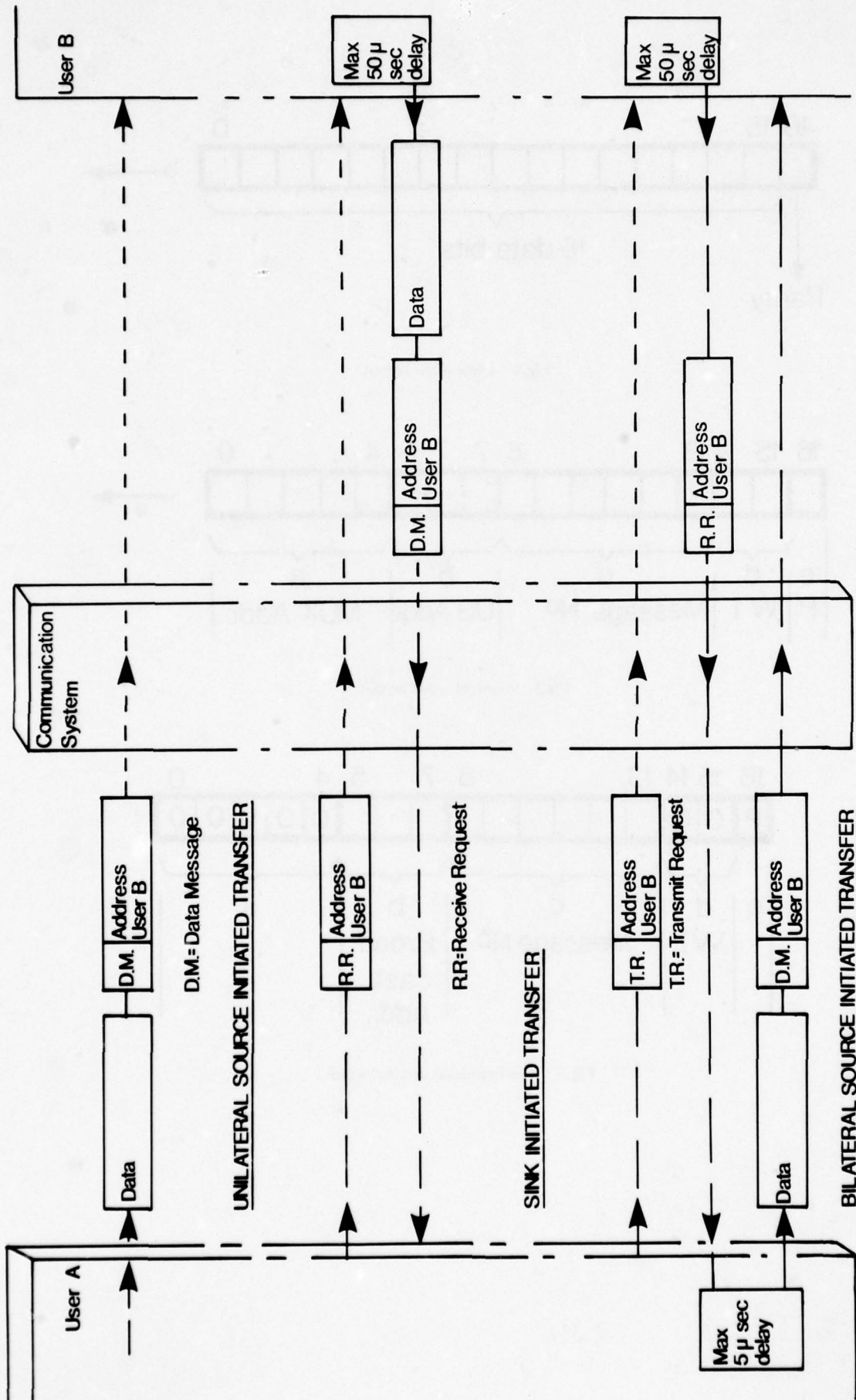


Fig.7 Message exchange protocol

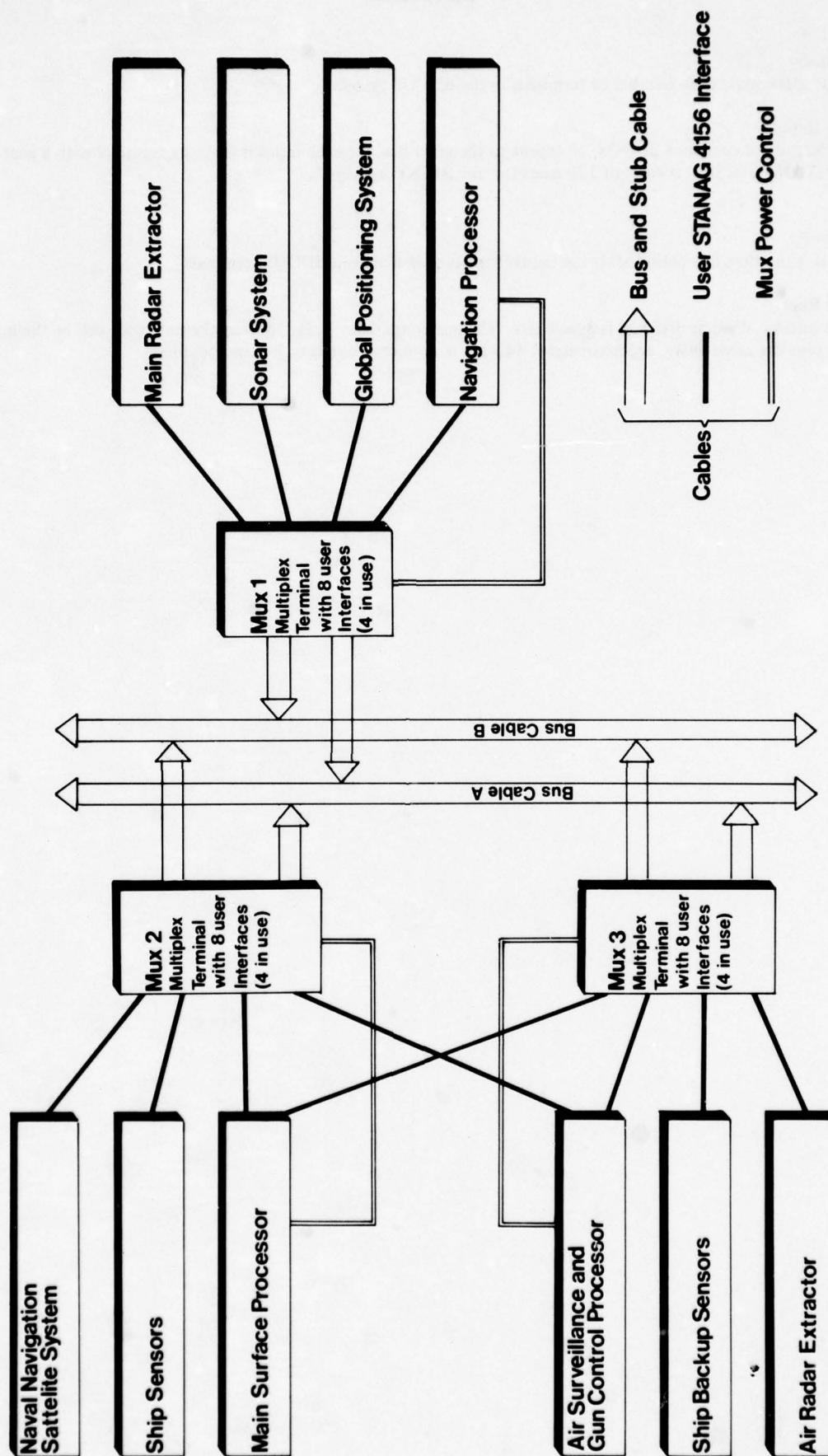


Fig.8 NAVVIS data bus system

DISCUSSION

M.G.Stainsby

What is the maximum number of terminals in the BUDOS system?

Author's Reply

In the present design of BUDOS, 15 inputs to the main bus, for each input it is a mux terminal with 8 user in/outputs (as STANAG 4156). A total of 120 users for one BUDOS system.

M.G.Stainsby

What is the time out period after the controller has polled a given BUDOS terminal?

Author's Reply

The interword gap in BUDOS is 3 to 4 bits. The minimum delay before polling the next user will be the interword gap plus the cable delay, approximately: $(4 \times 1/3 + 1)$ microseconds = $7/3$ microseconds.

ADNET: AN EXPERIMENTAL INFORMATION DISTRIBUTION SYSTEM

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SUMMARY

ADNET (Action Data Net) is a laboratory-based feasibility model of a shipborne command and control system. It is intended to allow examination and solution of problems associated with the introduction of distributed computing techniques to Naval systems in such a way as to allow flexibility of major weapon systems and reconfigurability of command functions. This paper describes the hardware implementation of the information distribution system around which ADNET is based, and which is in operation at the Admiralty Surface Weapons Establishment.

1. INTRODUCTION

The first implementations of computers in the Royal Navy, as with other Navies, were based on centralised architectures. Few options were available since the choice was made at a time when central processors were expensive and mini-computers unknown. This has resulted in systems which are inflexible and difficult to modify; in turn this exacerbates the problems of through-life support. A ship with a hull life of 20 years can be expected to benefit from significant weapon and sensor changes at least once in its lifetime. In centralised command and control systems such changes are rendered difficult by problems of modification of the large real-time control program in the central computer, and near impossible by the difficulties of renewing or altering significant amounts of the cabling which runs from individual weapons and sensors to the computer room.

ADNET (Action Data Net) is a laboratory model of a distributed command and control system which is being used (i) to prove feasibility of an efficient solution to the broad requirements for a flexible and modifiable command and control architecture (ii) to establish and resolve potential problems in assembling and maintaining such a structure. This paper is a description of the inter-computer communication highway around which ADNET is based and which is now set to work at ASWE. Though not described here in detail, work is proceeding on top-down distributed system design and structured software is being produced and tested on differing machines connected to the common highway.

When the problem of specifying a more suitable architecture was considered in ASWE, it was with a view to providing a solution that would allow more flexibility of the command system and easier major equipment modification than can be obtained with centralisation. It was appreciated that any solution would have to take account of the significant inter-computer communication problem which would arise from the introduction of distributed processing. It was also realised that information from major sensors onboard ship is of interest at a significant number of points in the command structure, and it was felt that any adopted communication system should have the capability of efficient multi-point distribution.

The overall strategy advocated has been to use a modular approach to software construction and test (MASCOT) which defines that software should be designed in terms of data flow between processes through formal interfaces and that synchronisation should be achieved through a standard kernel. A brief description of MASCOT appears elsewhere in these proceedings (Gladman et al 1978). Such kernels should appear in each computer involved in information dissemination or collection and, from an overall system point of view, it should not matter whether or not communicating processes are co-located in the same computer. By implication the inter-computer communication system should be at a level below application software, and, as near as possible, unseen by it.

The communication system, which has been built is in the form of a multidrop highway, as shown in Figure 1, to which all major weapon systems and command positions on the ship can connect. Access is governed by a highway controller through a set of specialist message protocols. Individual terminals polled by the controller must reply either with a data message or a nil response. Data messages are not addressed but are broadcast to all terminals, which accept or reject messages on the basis of a content descriptor, or message type byte, in the message header. Thus all information is available at all terminals and facilities exist for users to specify particular subsets for their own use.

2. HIGHWAY ARCHITECTURE

The highway consists of a single, overall screened, twisted pair cable, terminated at each end by its characteristic impedance. Connections from it are by means of high impedance transformers at the end of short spurs. To reduce vulnerability, where a terminal remote from the main highway is required, it may be connected by an active bi-directional spur, as shown in Figure 2.

The highway is built to interconnect distributed computers and, to achieve this, dedicated 'front-end' communication processors are used as terminals. These terminals have DMA capability to a limited part of their host computer's memory, as shown in Figure 3. The host computer may initialise, start or stop a terminal, as well as specify the message types that it wishes to receive from the highway. Line signalling, interpretation of protocols and error recovery are handled by the terminals and are invisible to the host computer. The terminals are specialist 8-bit processors, built around AMD 2901 bit-slice microprocessors and controlled by 32-bit wide microcode.

3. LINE SIGNALLING

Screened twisted pair cable and fully balanced driving are used to give noise immunity. The cable used is DRM-68, with measured sine-wave attenuation as shown in Figure 4. The terminals in use have been built with options to allow their configuration in a regenerative loop as shown in Figure 5, but all experiments to date have been conducted under multidrop working, and it is currently envisaged that it will be feasible to specify a ship system in this way.

The chosen modulation scheme is shown in Figure 6(a) and, though it is known in literature by a variety of names, is referred to in this application as Frequency Modulation or FM coding. The more widely used Manchester Coding waveform is shown in Figure 6(b) for comparison. Although the Manchester version gives slightly better performance against gaussian noise, the final choice of FM coding was based on the purely pragmatic grounds that it is insensitive to inversion of the 2 conductors during connector assembly. The FM coding of Figure 6(a) is violated only once, as shown in Figure 6(c), to give a unique end of message code. Line signalling rate is 3 Mbits/sec.

4. MESSAGE STRUCTURES

The highway operates by means of a formal set of message structures as shown in Figure 7. Each field is 8 bits long with the exceptions of SOM (16 bits) and DATA which is a multiple of 8 bits up to 248 bits total. Consider Message 7.1 ie a 'permission to transmit' message. The key to the structure of this is as follows:

- SOM This is a start of message flag and includes synchronisation bits.
- UMN 'Use Message Number' Issued by the controller. This will become the transmit message number when a terminal responds with a data message.
- HCB 'Hardware Control Byte' decoded by the receiving terminal to become 'permission to transmit' at a specific element on the ring. The top bit of this byte being set to zero indicates that no data message follows.
- ECB 'Error Check Byte' to allow a cyclic sum check to be performed.
- EOM 'End of Message'. This is a violation of normal coding rules thus allowing all data codes to be transmitted.

In figure 7.2, a 'short message' transmission in response to a 'permission to transmit' is construed as follows:

- SOM, ECB, EOM are as above.
- NAK Is an acknowledgement that the transmitting terminal has received correctly all message numbers up to NAK. Thus if $NAK = (UMN-1)$ all previous messages have been correctly received at that terminal. If $NAK < (UMN-1)$ then the highway controller will issue a repeat of the message ie NAK when it next has control of the highway.
- HCB Is as before and returns control to the highway controllers, save that the most significant bit being set to one indicates that a data message follows.
- TMN 'Transmit Message Number' is associated with the current data transmission, and is derived from the UMN of the 'permission to transmit' message.
- MTB 'Message Type Byte' is designated by software at the transmitting terminal and precedes the data content of any message.
- DATA Contains the message and may be of up to 248 bits long.

In similar fashion to the above, Message 7.3 is a reply from a data terminal with nothing to transmit.

5. HIGHWAY OPERATION

In normal working, the controller polls a terminal granting it "permission to transmit". The terminal responds, either by issuing a message which was awaiting transmission, or by sending a short "nothing to transmit" response. If the controller receives either of these responses without error a "permission to transmit" is directed at another terminal and the cycle continues. If the reply message from a terminal contains an error, the controller re-polls that terminal. (Immediate re-poll to a terminal which has just transmitted is interpreted by that terminal as a request for a repeat of its last message). The controller will try up to 4 times to obtain an error-free response from a terminal; repeated receipt of errors from a particular terminal will cause the highway controller to flag a fault condition.

In normal operation terminal responses will be error-free and each of the other terminals on the line will read each response and select or reject it according to the message-type byte. A wanted message is only validated at each terminal after that terminal has performed its own cyclic sum check. A copy of each message is, however, stored by the controller in a 'short term' message store to allow for the possibility that although the controller may have received a correct version, some terminals may have detected errors, perhaps because of local noise. In the event that a particular terminal's response to a "permission to transmit" indicates that it has received a previous message in error (ie its NAK counter is not at the current UMN value) the controller will issue a repeat of the required message from its short term store. Two further points are relevant to a complete appreciation of this procedure.

(a) It is not necessary to repeat all messages between the requested number and the current message number as terminals can continue to receive, even when a correct copy of a previous message has not been obtained.

(b) The message number handling and repeat procedures are functions of the controller and terminals only and are unseen by application software.

6. SOFTWARE INTERFACE

The host computer may initialise, start or stop a terminal by means of relevant peripheral control functions. Thereafter control and message input and output proceed through mutually accessed software tables such as shown in Figure 8(a) and (b). Message selection is controlled by the setting of individual bits in the message type byte table, which forms part of the primary table, shown in Figure 8(a). Setting of separate status masks for control of transmission and reception dictates the frequency with which the host computer should be interrupted.

Message flow in and out of host computer store is controlled by the input and output secondary tables of Figure 8(b). Thus a terminal which has been granted permission to transmit must check for the existence of a message in the next entry position in the output secondary table, while on reception the line terminal will store the next incoming message at the location indicated in the next position in the input secondary table. A host computer is expected to be aware of the state of the input secondary table and to ensure that locations for incoming messages are continuously available.

7. HIGHWAY CONTROLLER

Although it has a unique function within an ADNET system, the highway controller consists of identical hardware to the terminal boards, but with different microcode. In principle its reliance on a host computer is near zero and its function can be realised, in the existing design, with about 5K of random access memory and 10 words of read only memory. However much useful monitoring information about the state of the highway is available from status tables and the full benefits of this can more easily be realised by the use of a host processor. With this it is possible:

(a) To obtain short and long term history information about the performance of each terminal on the highway, both as a transmitter and also as a receiver.

(b) To alter dynamically both the order and frequency with which terminals are polled, either as a function of varying traffic loads or in response to some defined state requiring high priority access to be granted to particular terminals.

(c) To exclude completely from highway access a terminal which is responding unreliably or unintelligibly.

(d) To raise an operator alert, when a malfunction such as in (c) occurs.

In many applications the central processor load in any host computer associated with the controller will be light, and the task can be achieved by the installation of a second interface in a computer that already has a terminal. Maintenance of the control function is essential for successful operation of the highway and its continuance must be assured for shipborne use.

8. DISCUSSION

The foregoing description refers to the ADNET inter computer communication system that has been built and working within ASWE for about a year. In the sense that the initial aim of the system (ie reliable multipoint distribution) has been achieved the experiment has been a success. Early integration with distributed software is suggesting ways in which improvements can be effected, and at this point the basic concepts under which this was developed are being re-examined. This is possible because of the tremendous flexibility provided by the microcoded terminal processors, which means that the cost of implementation of a totally new set of highway message structures will be low - of the order of 8 man-weeks to produce the microcode, and perhaps another 6 to prove it. Thus it is possible seriously to consider:

(a) The introduction of 'block message working'.

(b) The introduction of more elaborate short message protocols better suited to the software structures of real-time distributed processing.

(c) The operation of the highway in contention mode ie without a highway controller.

The implications of these will be briefly discussed.

(1) Block Message Working

This facility was intended for inclusion in the original implementation. This will allow the transfer of data files, or program, along the highway on a point to point basis. Messages will be up to 256 bytes long and it is intended that they will be preceded by an acknowledgement from the proposed destination that it can accept the information.

(2) More Elaborate Protocols

It is envisaged that this highway will be used in a situation where certain tasks and functions are potentially migratory between differing physical locations. The totally broadcast method of working is suited to this environment, but it is felt there could also be advantages in retaining some physical addressing capability. Thus consideration is being given to the adoption of the message structure shown in Figure 9. Here 'Destination 1' and 'Source 1' are physical addresses, the latter being appended by the transmitting terminal. 'Destination 1' being set to zero would allow broadcast working as in the initial implementation, while at the other extreme, use of both source and both destination fields permits unambiguous point to point working between software processes in differing machines.

(3) Contention Working

The adopted poll and response method of highway access control gives some delays between message generations and transmission. Simulation shows these to be tolerable up to line loadings of the order of 65%. (In a cyclically polled 32 terminal system the average access delay will be of the order of 1 ms). It is recognised that these delays can be reduced by the adoption of a contention strategy such as in Ethernet (1) with a resulting increase in potentially available useful message transmission time due to the absence of polling messages. However the penalties to be borne, if contention working is used, are the lack of easy automatic error recovery and the inability to locate easily a defective terminal. It is believed that a maintainable and reliable ship system will be more easily achieved under a poll and response technique than in contention working.

9. CONCLUSIONS

The design aim of ADNET has been achieved ie the establishment of an inter computer communication system that will support but be virtually invisible to distributed application software, yet retain a high degree of flexibility and allow easy system expansion. It is recommended that control of such a system be vested in a dedicated controller, rather than on a distributed basis, to allow easy fault location and monitoring.

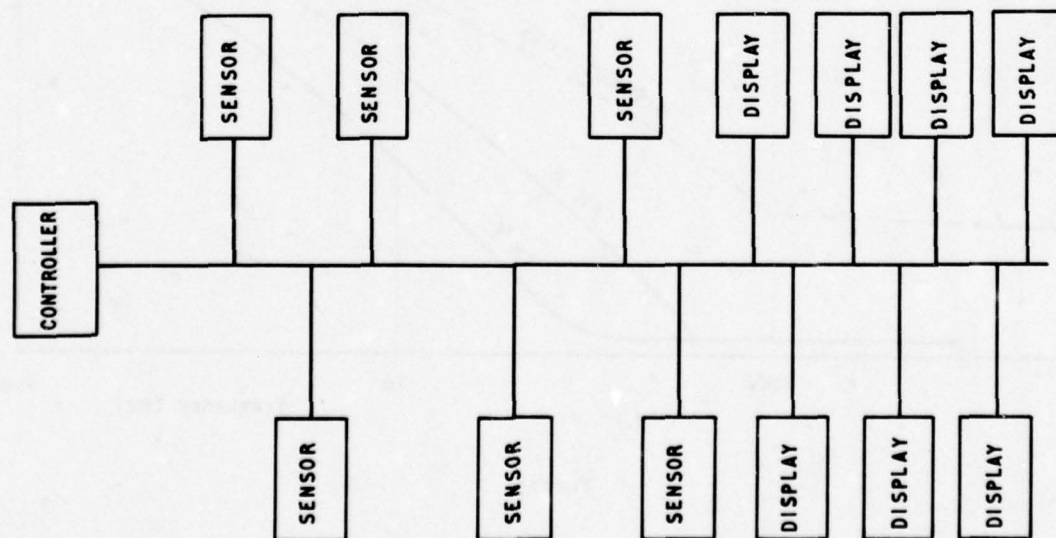


Figure 1

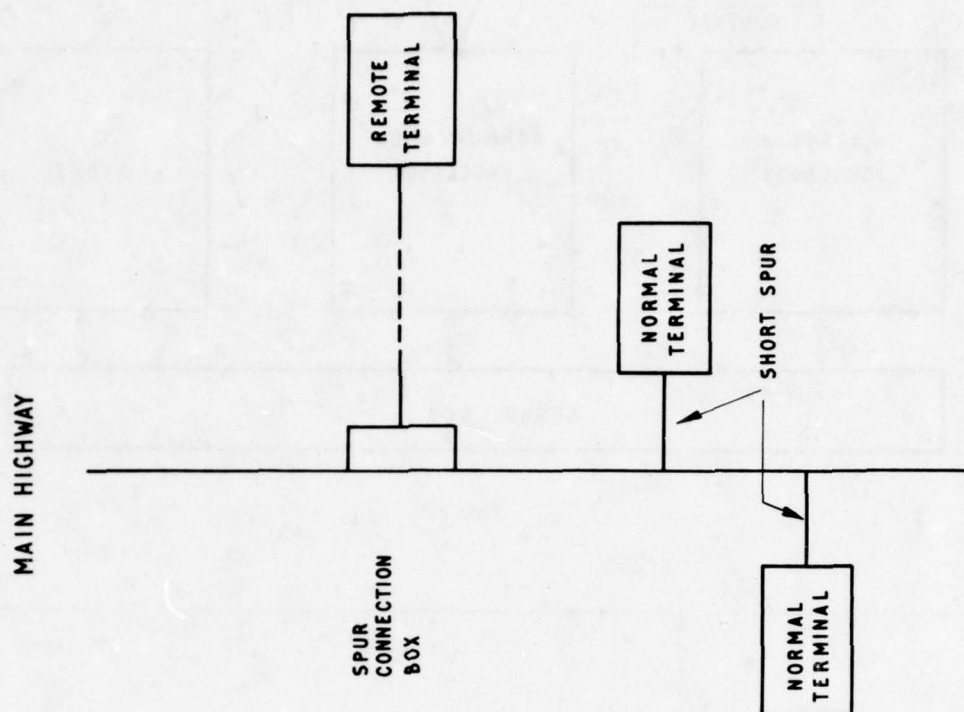


Figure 2

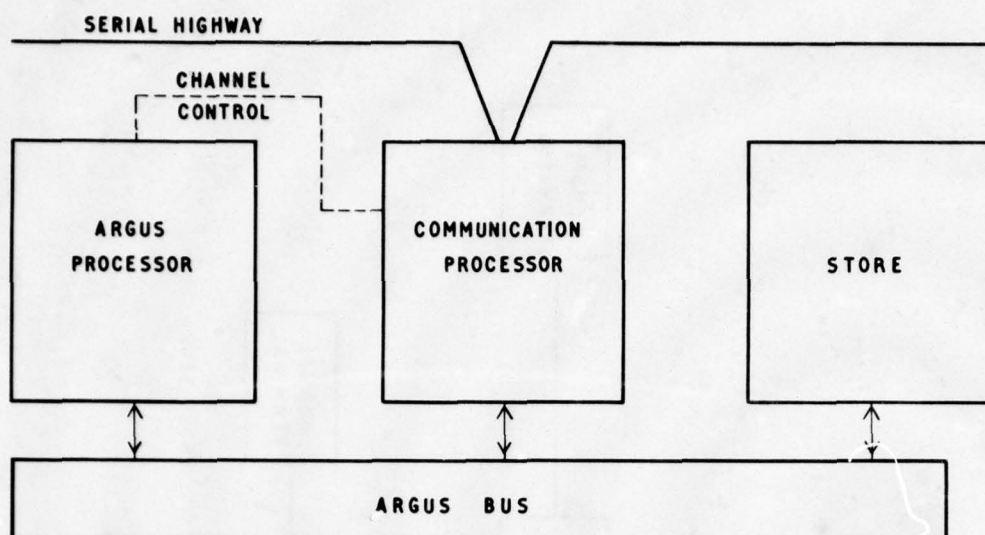


Figure 3

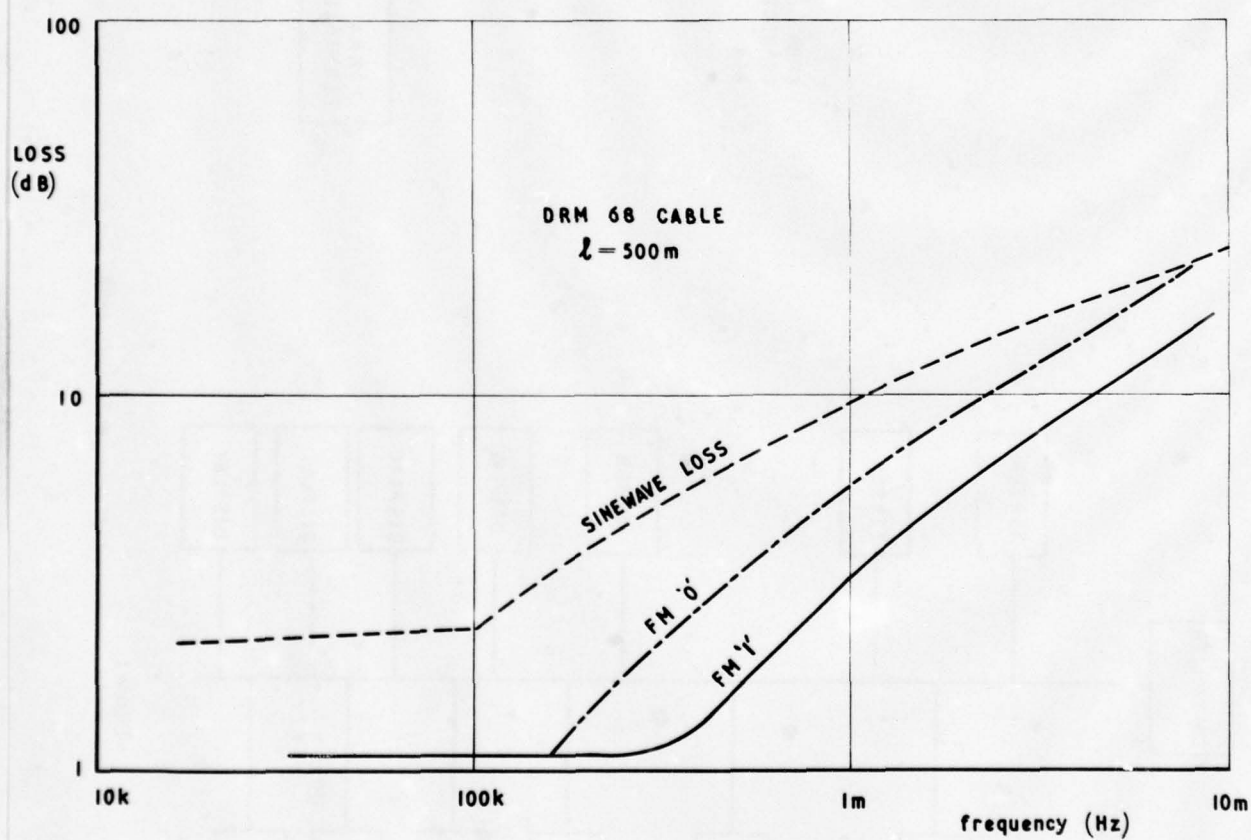


Figure 4

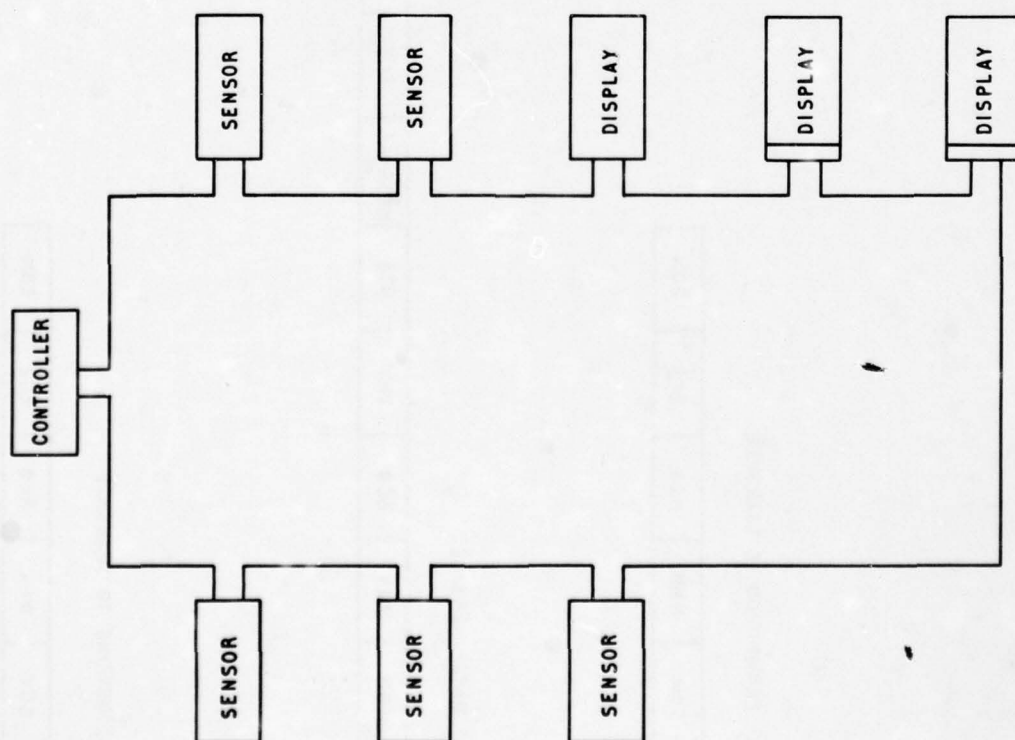


Figure 5

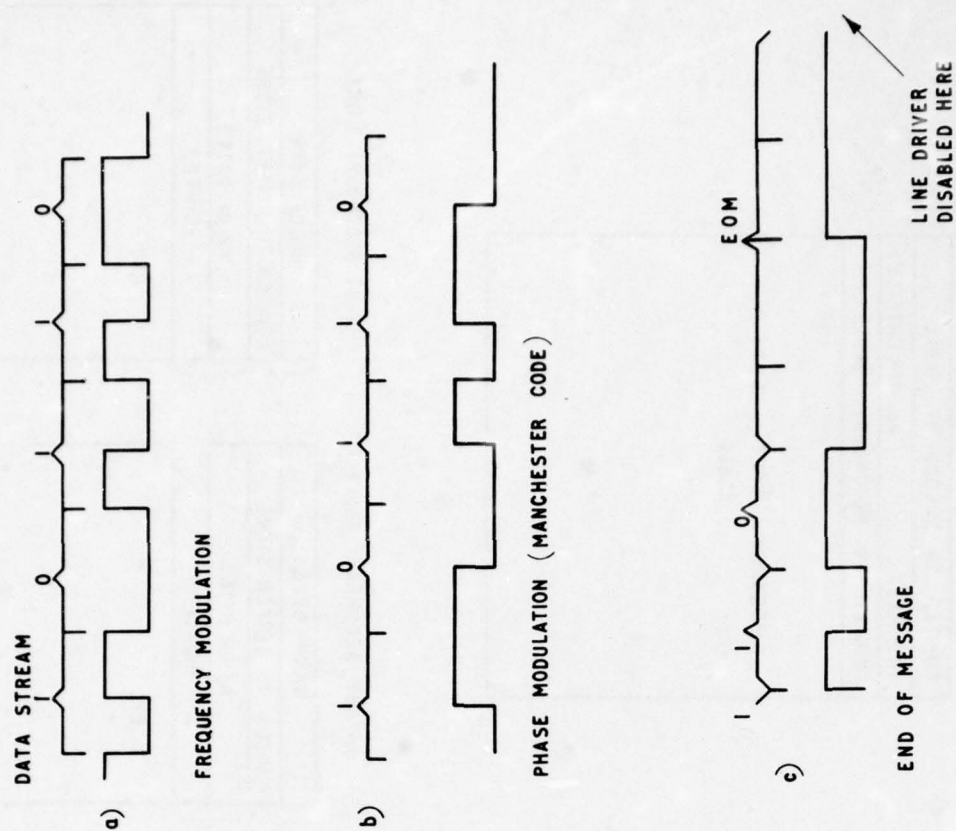
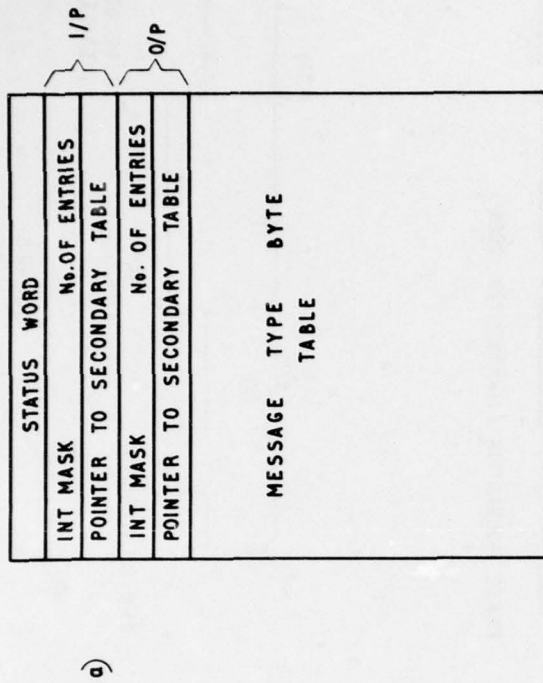


Figure 6



a) PERMISSION TO TRANSMIT

SOM	UMN	HCB	ECB	EOM
-----	-----	-----	-----	-----

b) DATA MESSAGE

SOM	NAK	HCB	TMN	MTB	MESSAGE	ECB	EOM
-----	-----	-----	-----	-----	---------	-----	-----

c) NOTHING TO TRANSMIT

SOM	NAK	HCB	ECB	EOM
-----	-----	-----	-----	-----

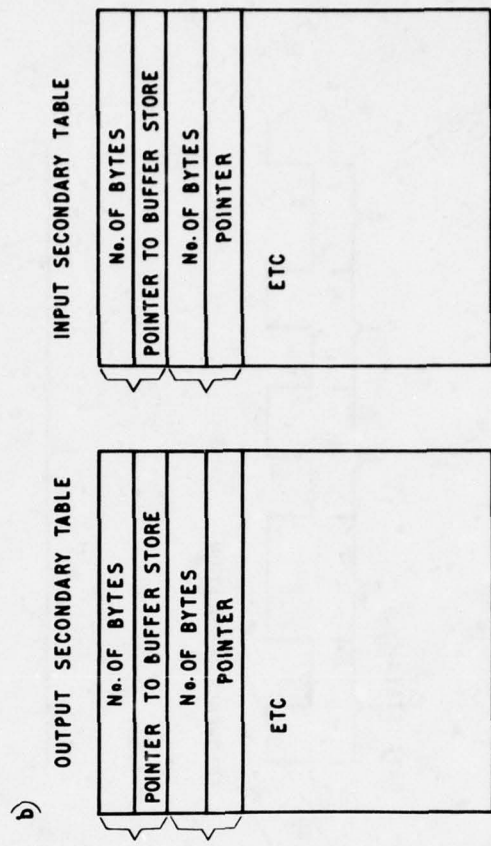


Figure 7

Figure 8

MODIFIED DATA MESSAGE FORMAT

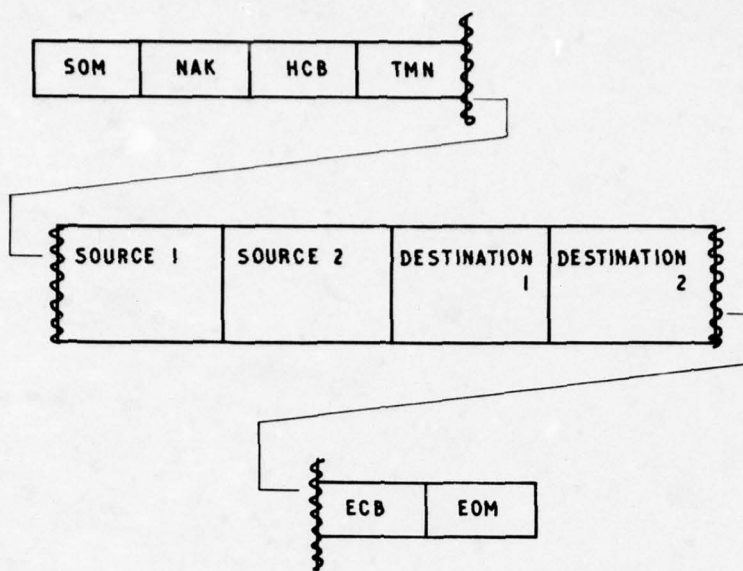


Figure 9

DISCUSSION

Kaltschmidt

I would like you to explain two phrases on one of your slides: High EMC Environment; fibre optics not suitable. Normally one thinks of using fibre-optical buses when the EMC problem is very serious.

Author's Reply

I would be pleased to use a fibre-optic highway when the technology to build a multidrop highway in fibre optics becomes possible. At present the loss in a fibre-optic tap is too high.

Rupprecht

Did you use any equalisers for your cables?

Author's Reply

No. You never know how far away the terminal you are trying to receive from is. For a given point-to-point link you can build an equaliser with no problem. For differing distances you would require an adaptive equaliser. We chose to try to improve our signal-to-noise ratios.

THE APPLICATION OF STRUCTURED DESIGN AND
DISTRIBUTED TECHNIQUES TO AVIONICS INFORMATION
PROCESSING ARCHITECTURES

by

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ABSTRACT

Structured design principles have been used in the formulation of a methodology for systems design and applied to the definition of avionics processing architectures. The task is an effort to take advantage of technology advances in the computer field and structured support in software to reduce life cycle costs of avionics. A core avionics is defined and the design constraint imposed upon it discussed. The structured procedure and the way in which it is meant to take advantage of technology is explained. Impact of standard is presented and a specified scheme for implementation. Alternatives for development and acquisition methods and contracting for a generic avionics core are presented.

Introduction

Structured design is a top down procedure which results in a near optimum software implementation of a set of performance traded functions. Optimum is primarily considered to be economic with performance and maintainability features traded. In general, it can be by any measure, since the design begins with a selection of prioritized design criterion particular to the system such as A/C avionics. Traded functions refer to subsystem and system mode functions along with their algorithms for the most part which are bounded, optimized and traded off to some performance measure as might be done in researching tracking or detection algorithms. Since avionic systems can represent a set of defined and bounded functions within a mission and are normally designed to strict constraints and criterion, they can lend themselves to implementation via a more structured approach than has been used in the past, and which may be possible in larger less constrained systems. It is somewhat of a marked departure from previous integration procedures. Most past design philosophies avoid the risk of advanced technology in favor of low risk integration of present technology which has resulted in unique and complex integration configurations and associated high costs. The definitions herein and the structured engineering procedure suggested serve as an introduction to a unified approach to system design utilizing common architectural concepts, interfaces, and new technologies which used effectively can achieve lower life cycle cost in future avionics. It represents a wider application of structured design than its original software programming intent but with similar objectives. Some history may clarify the motivation in light of the economics of complex weapon system acquisition existing today. The first figure is an illustration of the evolution of avionics system implementation over three decades. In regard to processing of both data and signals in the 1950's, and prior, we saw independent self supporting subsystems competitively procured and installed with very little intra-subsystem data flow. Each major subsystem usually required an independent operator console and interface. Only obvious interfaces and data transfer occurred. As computers entered the scene, their primary use was in heavy computational modes as navigation and autopilot systems, and then on into sensor subsystems and into signal processing computations. The 1960's evolved the software packages such that generalized computations for all subsystems moved into multiplexed centralized computers with both non-real time and real time interfaces. This was an effort to save the cost, weight, and size of computer hardware and consolidate computer program and data handling. However, because of mode expansion it generated a cost growth problem in complex software generation and software support, particularly when within the same system different manufacturers' computers were used, it required use of multiple languages, various software interconnect schemes, software support systems, and software maintenance tools. Avionic systems are not alone in this evolution, but feel the impact of the problem to a greater degree when both mission and subsystem functions are expanded. The technology advances experienced in the 70's show trends toward reversing this evolution due to the availability of small, inexpensive, low power, light weight processors capable of meeting 95% of the speed requirements and offering a host of advantages very appropriate to avionics. Designs cannot return to complete independence, since this same period has seen the growth of intra-subsystem dependence and real time interfaces for data and signal correlation, and assimilation, and the resulting increase in subsystem communications. For example, the operational program in the P-3C alone has grown by 35% in one decade primarily due to expansion of sensor subsystem modes. Figure 2 is an example of central computer usage where data from all subsystems is assimilated, even though signal processors are used in each subsystem. When computing power is added by adding additional processors to pick up expanded modes the usual circumstances is introduction of additional software support schemes, problems in data communication, I/O compatibility, program and data linking, protocol, etc, making programming debugging and running difficult and expensive, with logistics and maintenance poor. However, this is primarily because a program structure is unique and difficult to modify without great expense and complex control

schemes. Several technology advances within this decade now allow us to tailor processing resources to the various tasks rather than to determine as best we can what will fit into available resources, allowing for planned reserve and expansion, without cost growth. In the list of major advances we must include LSI microprocessors, microprogramming techniques, advances technology memory devices, CCD functional hardware, software interface and macro techniques, HOL deficiency improvements, techniques for human function automation, self diagnostics, and especially the techniques for distributing computer resources and distributing processes by shared or dedicated processing units or memory and the ability to use in these networks functional module hardware.

Our goal is to arrive at a procedure for avionics design by which we can combine the aspects of a structured design, with the advantages of the techniques of implementation in advanced technology while incorporating concepts of distributing computer resources. Lets begin by looking at the characteristics of all these areas and then to their marriage via a design procedure guided by system constraints. This marriage is the essence of the procedure and the means by which we can implement the improvements in avionics, at each level and combined levels of functional modularity, e.g., system subsystem, mode in subsystem, function or mission.

Characteristics of Structured Design

Fundamental to a structured design is the breaking up, partitioning or decomposition of system functions into separated modules. Modularization has been defined as the decomposition of large functions into small functions in an organized manner. In the software structure, modularity is used to invoke conventions in programming techniques and standard interfaced of program segments to make coding, control, debugging, expansion and maintenance easier and less costly. Characteristics of a structured design therefore are (figure 3):

1. A method of decomposition into modules of system functions.
2. Imposition of standards.
3. Methods of structuring segmented functions.
4. A design criterion for selection of standards and module interfaces.

In addition, in applying the procedure to not only software but hardware and firmware we require as new technology might dictate:

1. Allocation criterion for hardware/software/firmware.
2. Hardware interface definitions.
3. Procedure for incorporating constraints of the system which influence the above.
4. Relationships in a language to firmware/hardware modules.

Modularity of this nature brings with it several significant advantages in design which relate directly to system improvements and can form inputs to our list of design criterion. Some advantages (figure 4) are ease of modification, multiple use of modules (transportability), simplified structured programming, simplification of software by hardware instructions which reduce program complexity, increased reliability.

In relation to avionics design modularity can be defined functionally, or in relation to subsystems or mission. This is illustrated in the matrix shown as figure 5 of subsystem/function breakdown. Another way of looking at a top level is to associate subsystems and functions relative to the primary mission which they perform, ASW, AEW, TACAIR surveillance, etc, vs functions of the mission. A generic way of forming avionics modules is to consider mission independent functions and subsystems (the consistent intersection of the mission and subsystem matrices) of core avionics on which to build a variety of mission responsive systems. Core avionics include;

- Navigation
- Communications
- Info/Data/signal Processing Architectures
- Flight Control
- Flight Instruments
- Displays/Controls
- Electrical Power
- Fueling System
- Stores System

The avionics information processing architecture is the means by which core and mission particular avionics are interfaced via a networking of component resources, data/signal distribution and control methodology, using standard interfaces, and protocols. Our process goal is to decompose toward modules at lower levels implementable in single form, interconnected to form subsystem/system functions. The impact of this decomposition is seen mostly in installation, configuration, software

16-9

and maintenance costs. The lowest level of module is the microcoded function in a form allocated to hardware firmware or software control. The decomposition occurs primarily in subsystems but intra/subsystem and tactical functions are of importance to successful system implementation. The partitioning of core and mission functions serves to define the role of processing architecture and processor interconnect network. A new different techniques for function decomposition have been developed which can apply to the avionics process in line with a design criterion. We first list such criterion and typical avionics characteristics and constraints. A criterion (figure 6) can be formed in several aspects of the design, software, maintenance, modularity and core system definition, hardware, etc.

- . Wherever possible simplify software implementation and support
- . Consider language standards
- . Software interface standards
- . Replacement by functional hardware/firmware
- . Partitioning of executive functions
- . Provide portability of software
- . Consolidate support software and configuration management
- . Incorporate self diagnostics
- . Incorporate complete fault isolation
- . Provide 30% growth in functional expansion
- . Design 20% reserve in resources
- . Reduce weight 25%
- . Automate all mundane operator functions
- . Warranty provisions
- . Design with minimum count
- . Design for minimum operator interfaces
- . Design degraded modes with automated recovery responses
- . Design for minimum intra subsystem communications
- . Design flexibility in processor allocation
- . Design adaptability of specified functions
- . Design portability of software to new technology hardware
- . Design recovery modes as opposed to redundant modes or vice versa
 - cold standby - radar, acoustics, etc
 - warm standby - communications, navigation
 - Gaust modes (command, control)
 - memory sharing
 - back up programs for reduced modes
 - redundant power sources
- . Error detection/checking/correction
- . Establish product improvement categories and lines
- . Establish standard hardware interfaces between subsystem in A/C particularly
 - Radar
 - Sonar
 - MAD
 - Optics
- . Provide automatic prompting of crew in flight control and mission operations
- . Provide appropriate criterion for design of each subsystem

Typical avionics constraints are listed as mission sensitive parameters which must be addressed in selection of both core and mission subsystem design and directly influence the design features in the processing architecture. For example, in an ASW mission (figure 7):

- . Real time processing and real time interfaces
- . Dynamic correlation between sensor system data, radar, acoustics, navigation, magnetics, optical-IR, for tracking, update, fixing
- . Processor and memory requirements are bounded and generally non volatile
- . Physical weight characteristic limitations
- . Power consumption limitations
- . EMI requirements
- . Heat/air conditioning requirements
- . Reliability MTBF
NTTR requirements
- . ILS limitations - life cycle support time (20 yrs)
- . Processor speed requirements
- . Memory size requirements
- . Data transfer rates
- . Cost limitations
- . Maintenance environment limitations
- . Prioritization of computer resource uses and subsystem interface data, degraded mode priority
 - Communication
 - Navigation
 - Radar
- . Risk thresholds for each mode
- . Autonomous radar operation and navigation operation

In applying a decomposition or partitioning of function for implementation, the techniques used must be in accord with the composite intent of these constraints and criterion and allow for incorporation of priorities.

Decomposition Methods

Techniques for decomposition have been primarily developed for software program segmenting with the objective of program interface simplification and convention (figure 8). Different techniques will result in different modularity at the implementation level and can result in different recommended structure of programs or computer networks and media. Work at Carnegie-Mellon University (reference (a)) was directed at a technique which maximizes the independence of program modules with well defined interfaces for the purpose of reducing programming effort. It addresses the methods of handling data and program in parallel or sequentially and may or may not result in modules which resemble steps in the functional algorithm process or steps in the computation in a signal data or decision flow chart. Thus it addresses software programming on a general purpose device, and does not directly pursue modularity for the coupling of hardware, software, and firmware in one composite implementation, nor for embodying real time signal flow sequences as would be programmed for signal processing by signal processor designers. For our tactical processor implementation in avionics environment it is desirable and to our advantage to associate the partitioned elements in a manner as to directly support efficient running of the functional process. The process being a completely executable entity embodied either in hardware, software and/or firmware segments whichever serves its needs best to fulfill the criterion imposed. Univac under Navy sponsorship has been pursuing such decomposition techniques based upon functional dependence in data flow and control and upon sequential or parallel execution, priority, shared resource, timing to result in a structure of elements which can be appropriately mapped into the three media and permitting the development of a library of many stand alone functions which can satisfy several applications in avionics subsystems and to tactical functions. After decomposition into elements, a dependency structure is generated which allows assessment of implementation media and the most economical networking of resources for implementation when again coupled with the design constraints of the system. It also structures the control mechanism for resources and therefore outlines executive design. When functional elements require the same resources (memory, operation, control) we can well arrive at a networking which resembles present multiplexed

programming. When unique and independent elements emerge they may be implemented in a distributed manner where the data and resource requirements are met. This brings us to the step in the partition process of a decision whether to implement a functional segment in hardware, software or firmware. A list of a medium advantage is shown in figure 9. Criterion by which the assignment is made is indicated in figure 10. Firmware is a means of implementing partitioned programs in a rigid manner by permanently burning in ROM or semi permanently in PROM or EAROM. It may require more steps than software to implement or less instructions to actuate. It therefore is not as readily adaptable or modifiable as software, but can serve as a simplification to overall programming when acting as a primitive macro or implemented subroutine. In this manner it approaches the performance of hardware compromising the flexibility of software. Its reliability is a function of the programming conventions used and the quality control exercised. For the above reasons firmware implemented using LSI microprocessor technology has become popular for embedded function replacement acting as hardware, yet adaptable upon ROM replacement. If we look at the typical ways in which microprocessors are used in avionics we see a range from functional replacement as program implementation, or data traffic control to small scale programmable processor implementation with microprogrammed instructions. The latter replacement done primarily to lower cost. An example of this application in avionics (for communications control) is shown in figure 11, where logic switching of RF and modem techniques are controlled. Other applications for example in memory control functions, microprocessor control can eliminate latency time and allow more task overlays, minimize main memory usage.

Of interest to a structured design are alternate methods of software support for microprocessor program generation and configuration control. Functional replacements which require no software support and which modify or replace logic can be designed solely by functional and interface specifications. This functional mechanism can also include implementations of primitive functions for larger scale computing. General CP utilization of microprocessors requires support of language, and language processors. A language hierarchy is shown in figure 12. Most appropriate for efficiency is a machine oriented language, however it compromises the portability to other machines of newer technology. More advantageous is a problem oriented high level language with macros or subroutines related to system design or functional design as in the case of signal processing routines common to sensor signal filtering, detection, tracking, etc. It is estimated that such language would cover 95% of the real time applications with primitive functions. A set of guideline specifications by which subroutines can be written in mnemonics and later included in a library under control of a HL problem oriented language would serve this implementation well. This procedure is being incorporated in the acoustic processing routine for PROTEUS using SPL-1, and is feasible to extend for microprocessor routines in real or non real time system programming.

System Structure and Computer Networking

We are now at a point in the design process where we have partitioned system functional algorithms into elemental program units as would be done in flow chart form, compiled their interdependencies, simplified the latter by iteration of the decomposition process, and assigned each program element to an appropriate implementation in hardware software or firmware in accord with criterion. The structured data flow and control requirements of the decomposed functions will allow us to construct a processing network of resources, processors, memory, (ROM RAM), bus and associated operating system. It now remains to structure the elements into an executable design, and relate such a structure of program elements to a networking of processor resources and produce executive functions which control and schedule their execution within the network. The network resources, processors, memory, I/O channels, communications interfaces and programmable or ROM controllers are selected and connected on the basis of required speed, storage, data transfer paths, task allocation, and the design constraints. To consider networking resources without these considerations and particularly the feasibility of executive design is sheer folly and to a degree is responsible for complex traffic problems even in the most elementary control processing network. However, we have not let this fact discourage our creativity and in figure 13, reference (c), we see the universal computer resource network. The direct I/O, memory transfer can be implemented with microprocessor logic control, and also with memory to memory transfer. Considering only one processor and memory, with processor, I/O, and memory processor data transfer a central multiplexed uniprocessor results. Configuring multiple units with processor to processor data transfer, and multi memory access and multiple I/O processor access results in tandem multiprocessing a parallel dedicated or redundant processing capability. Still another configuration, the distributed network results when processors have access to all memories and are directly related to one I/O channel.

When considered for either avionic subsystem or system use this configuration offers the most flexibility in the partitioning and allocation of functional program units to software, firmware or new technology hardware since data is passed efficiently to each processor which can be related via appropriate calling sequences. Processors can be general purpose (programmable) or special purpose (ROM or hardware). This approach is most efficient and finds modern use in achieving efficiencies for multisensor signal processing with simplified programming. A final federated configuration results when the only transfer path is at the I/O level and processor and their associated memory are independently programmed and operated. No programs are shared or transferred between processors. In federation, redundancy is

only capable by virtue of duplication. Considering the utility in avionics, figure 14 shows a tandem configuration for networking within a dual radar subsystem. In most platforms where space and weight are not at a premium normally dual systems would be built and only share control or console displays. Here parallel operation of normal modes are designed with sequential operation of demand modes or recovery modes in accord with design constraints, although reserve and growth can be attained by providing increased processor throughput and memory or additional processor interconnection. Special purpose hardware is not ruled out but in this case can imply more complex executive control and scheduling. Depending upon special sensor interconnect requirements hardware can become expensive in design, not necessarily in production. It is appropriate for using an AN/AYK-14 device with programmed I/O and multiple memory parts, with memory controllers. Because of the above it is easy to recognize that careful functional radar mode partitioning is required here, and would generally be done by its designer in a unique manner, using unique software or hardware for achieving signal processing efficiency with reduced overhead. The flexibility and expandability of this network in the design are directly traded for executive complexity. Next consider a mission related sensor subsystem composed of acoustics, MAD, IR and optical sensors interprocessed on a distributed subsystem with options of sequential or parallel processing in accord with sequential mission modes (figure 15). The appropriateness of the bus network here cannot be over emphasized since federation, although requiring a less complex executive is cumbersome for buffering and transfer if multisensor data via multiple I/O ports. Here alteration and reconfiguration is feasible because processing programs used in multiple sensors can be shared by multiple processor and partitioning has potential for drastic simplifications. Kalman tracking algorithms utilizing both acoustic and optical or MAD data can be effected with little signal or data transfer. Data from any sensor or sensors in combination is readily available for correlation and display. The structure and the network support extensive expansion for reserve or added modes. Considering the total of subsystems in avionics and the characteristics loading and design constraints of each one may assign networks in the following manner.

Communications	- distributed
Navigation	- tandem
Radar	- tandem
Acoustics, Magnetics, Optics	- distributed
ECM/ESM	- federated
Stores	- central redundant, etc

The overall networking which integrates subsystems must for simplicity be termed distributed with selective task allocations, figure 16. These schemes of networking can then be divided into our original module concept of core and mission avionics as appropriate and this hybrid planetary system is what appears to support avionics subsystems most economically with least projected overhead. Emphasizing that detail implementation demands the structured procedure. This is shown in chart form in figure 17. Partitioning, simulation and/or emulation must be iterated to evaluate and finalize design. The overall performance of the design would naturally be judged by its cost and performance trade and how well it met design criterion such as was presented earlier. To name a few, measurable quantities, mission reliability, parts count, adaptability, data flow, executive complexity and overhead, technology independence, etc.

Summary

Reflecting on the proposed process we might ask the following questions. Is this a vastly different process for system design? Is it realistic and/or risky? Does it represent an entirely new way of specifying and procuring avionics? One question at a time! I might contend that the process is reproduced in one manner or another in any system design however unstructured and that functional implementation, and cost tradeoffs are made non-the-less or may be to less advantage than can be done with a formal structured approach. Secondly, realism is today's motto in all realms, and if the technical capacity is not present our most virtuous goals are not attainable. Each technology involved in this process is available to us during the 1975-1985 time period. I believe it is still the virtue and initial cost that we debate to a fault. Third, it does represent a new approach and its many features among the most dominant is the fact that independent thinking designers are forced at the onset to admit dependence to a benefit and not a hindering, and it is in the interdependence of the integrated design itself that value is gained in adapting standards and a common structured procedure in engineering each subsystem although possibly contracted and negotiated separately. This design projection and process may appear to prevent competition in procurement or limit design options. Figure 18, I hope, will show that in reality it is challenging design creativity to define standard economically implementable structures of functions and merely preventing definition of such challenged response as competitive edge.

Observations which we think can be made from the above discussion include the following:

. One of the most realistic techniques for simplification and reduction of software generation and maintenance costs as well as system implementation and integration costs beyond the use of common software support and language is the partitioning of system and subsystem functions so as to structure algorithm elements assignable to the most economic and appropriate implementation commensurate with media advantages and mission aircraft design constraints.

. Problem oriented languages and macros primitive to system algorithm functions go a long way in assuring program reproduction, transportability and expansion cost reduction, particularly in microprocessor design and programming.

. A method of processor and peripheral device networking does not of itself constitute architectural completeness, but must be done in consort with structured partitioning, device modularity and A/C design constraints and must be such as to allow feasibility of executive functions without overburdening complexity.

. Avionic systems, by virtue of a variety of missions and peculiar functional approaches to core and mission subsystem design constraints are best supported by a planetary network of hybrid structures, and subsystem networks unified by multipurpose connective buses at subsystem and system levels.

. Structured partitioning techniques, interdependence definition, and composition of algorithmic functions into realistic implementable elements offers the strongest and most realistic approach to uniting the advantages of LSI technology, language interfaces, and distributed resource techniques to accomplishing economical next generation avionics systems.

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- (c) Avionics Information Processing System Design Methodology H. Freeman and E. Christiansen, Sperry Univac for Naval Air Development Center, March 1977
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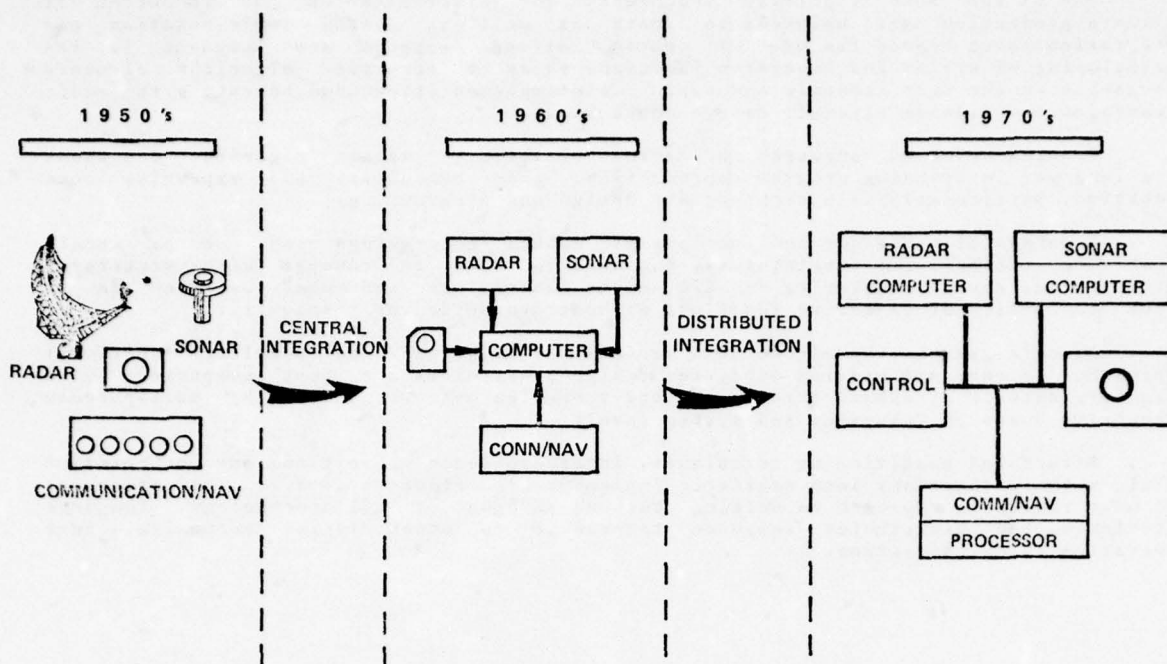


FIGURE 1 - EVOLUTION OF AVIONICS PROCESSING

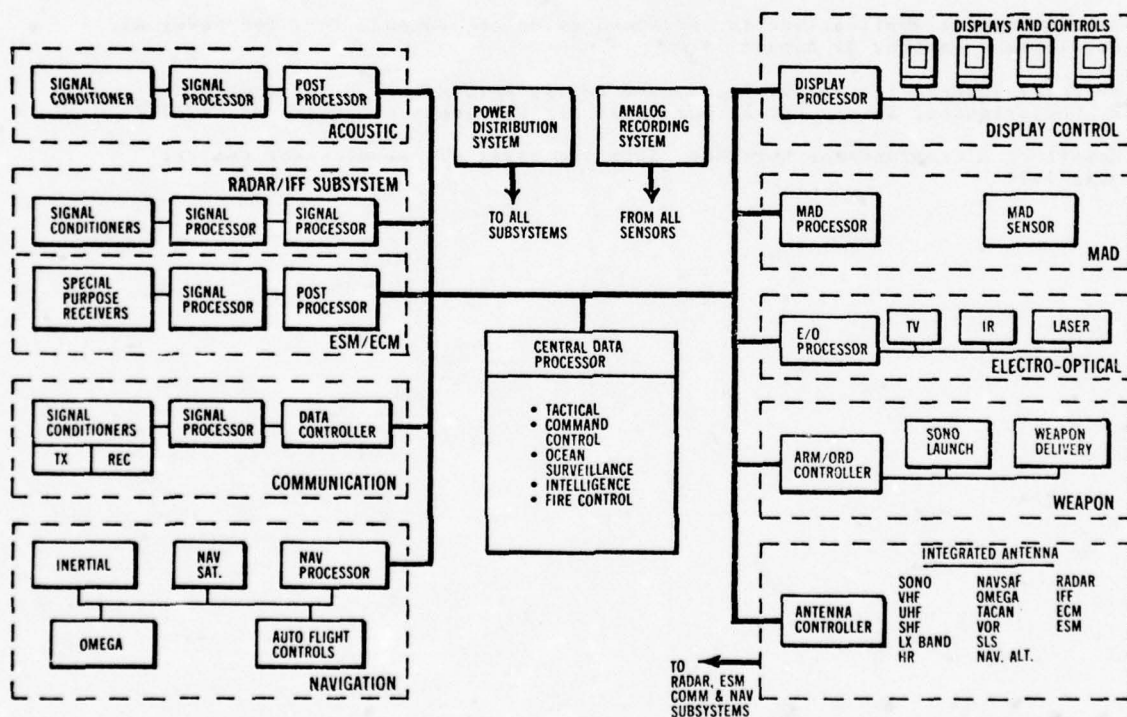


FIGURE 2 - SYSTEM APPLICATIONS

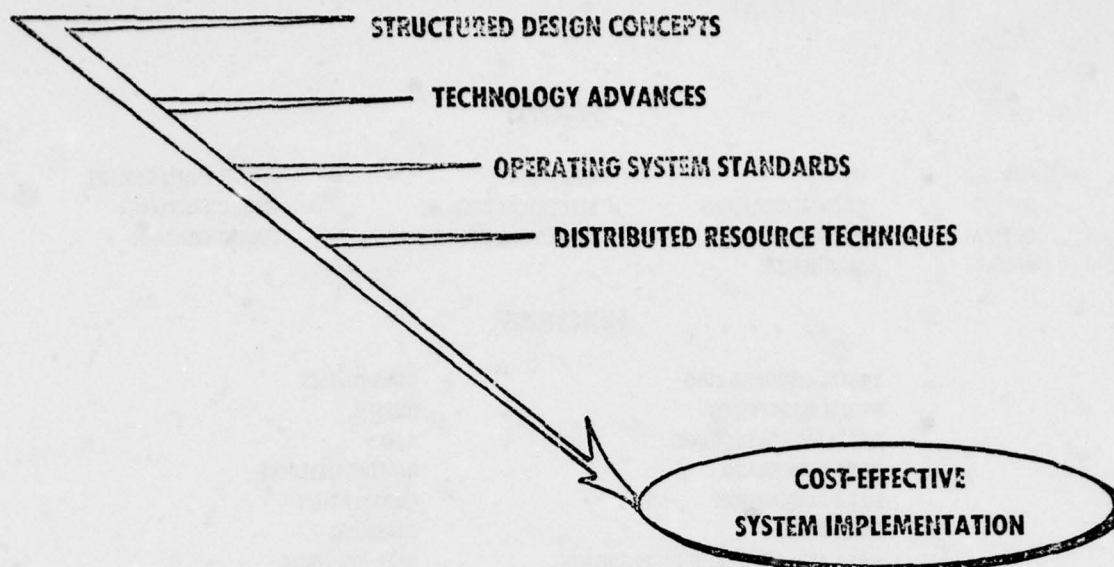


FIGURE 2A - COST EFFECTIVE SYSTEM IMPLEMENTATION

- MODULARITY
- REDUCED INTERDEPENDENCE
- SIMPLIFIED PROGRAM LINKING
- EASY EXTENDABILITY
- COMMON PROGRAMMING CONVENTIONS
- EXECUTION TIME VS. MEMORY OVERHEAD
- COUPLING — LOGICAL - FUNCTIONAL
TEMPORAL - SEQUENTIAL

FIGURE 3 - CONCEPTS OF STRUCTURED DESIGN

ELEMENTS

DECOMPOSITION METHOD
 OPERATING SYSTEM STDS.
 DESIGN CRITERION
 ALLOCATION CRITERION
 HDW. INTERFACE STDS.
 SYSTEM CONSTRAINTS

ADVANTAGES

MODIFICATION/DEBUG EASE
 TRANSPORTABILITY
 PROGRAMMING COSTS REDUCED
 RELIABILITY IMPROVED
 DOCUMENTATION SIMPLIFIED
 LANGUAGE EFFECTIVENESS
 MEDIA INDIFFERENCE

FIGURE 4 - STRUCTURED (HDW SWT FWM) DESIGN

SYSTEMS

FLIR
IFF
OPTICAL
RADAR

**IFF
COMMUNICATIONS
ACOUSTICS
MAGNETICS**

**CSM/ECM
ELECTRICAL DIST
DISPLAYS & CONTROLS**

**STORES MANAGEMENT
WEAPON DELIVERY
ENGINE CONTROL**

FUNCTIONS

SIGNAL CONDITIONING
SIGNAL PROCESSING
DATA/SIGNAL STORAGE
DATA PROCESSING
DATA ACQUISITION
DATA DISPLAY
DATA AND COMMAND DISTRIBUTION
INPUT/OUTPUT COMMUNICATIONS
CONTROL
TEST
DECISION MAKING
OPERATOR INTERFACE
HOUSEKEEPING

**DIAGNOSTICS
BUFFER
A/D
DIGITAL FILTERING
CORRELATION
TRACKING
DECISION LOGIC
KALMAN FILTERING
FFT
DETECT
SORT
FORMAT**

FIGURE 5 - MATRIX OF AVIONIC SYSTEMS/FUNCTIONS

- **CONSOLIDATE SUPPORT SOFTWARE**
- **PROVIDE PORTABILITY**
- **SIMPLIFY EXECUTIVE FUNCTIONS**
- **IMPOSE LANGUAGE STDS STUDIES**
- **WEIGHT COST IN IMPLEMENTATION MEDIA**
- **PROVIDE 30 % RESERVE 40 % GROWTH**
- **REDUCE COMPOSITE WEIGHT BY 25 %**
- **AUTOMATE ALL MUNDANE OPERATOR FUNCTIONS**
- **MINIMUM COUNT**
- **MINIMUM OPERATOR INTERFACES**
- **AUTOMATED RECOVERY MODES**
- **BACKUP MODES — NAV — WARM STANDBY ALL MODES**
COMM — WARM STANDBY ALL MODES
RADAR — COLD STANDBY REDUCED MODES
- **ERROR/FAULT DETECTION**
- **AUTOMATED PROMPTING IN TACTICAL MODES**

FIGURE 6 - DESIGN CRITERIA

- REAL TIME PROCESSING & REAL TIME INTERFACES
- DYNAMIC CORRELATION BETWEEN SYSTEM DATA
- MEMORY & PROCESSOR SPEED BOUNDED APRIORI
- SERIOUS PHYSICAL WEIGHT LIMITATIONS
- SERIOUS POWER CONSUMPTION LIMITATIONS
- EMI REQUIREMENTS
- HEAT/AIR CONDITIONING REQUIREMENTS
- HIGH RELIABILITY NEEDS
- ILS LIMITATIONS
- MAINTENANCE LIMITATIONS
- PRIORITIZED SUBSYSTEMS
- LIMITED ON STATION TIME

FIGURE 7 - AVIONIC DESIGN CONSTRAINTS

CARNEGIE-MELLON

- INDEPENDENCE IN MODULES
- SOFTWARE
- NOT NECESSARILY PROCESS ORIENTED
- GENERAL PURPOSE DEVICES/PROGRAMMING

UNIVAC

- STRUCTURED MODULES / DEPENDENCE HIERARCHY
- SOFTWARE/FIRMWARE/HARDWARE
- PROCESS ORIENTED/PRIORITIZED
- SHARED OR DEDICATED RESOURCES
- GENERAL PURPOSE AND FUNCTIONAL
- VARIATIONS IN STRUCTURE VS. - CRITERION/CONSTRAINTS

FIGURE 8 - METHODS OF DECOMPOSITION

	<u>FLEXIBILITY</u>	<u>MODS</u>	<u>COST</u>	<u>RELIABILITY</u>	<u>THROUGHPUT</u>	<u>MEMORY</u>
HARDWARE	LEAST	HARD	LOW	HIGH	HIGH	LOW
FIRMWARE	MORE	MEDIUM	LOWER	BETTER THAN SOFTWARE HIGH	HIGH	MEDIUM
SOFTWARE	MOST	EASY ADAPTED	HIGH	LOWER (CHECKOUT)	LOWEST	HIGH

FIGURE 9 - IMPLEMENTATION MEDIA ADVANTAGES

HARDWARESOFTWAREFIRMWARE

DATA FLOW
 COST
 EXPANDABILITY
 TRANSPORTABILITY
 LIFE CYCLE COST
 DUPLICATION
 SHARED DATA/RESOURCES
 RELIABILITY
 THROUGHPUT
 COMPLEXITY
 CONCURRENCY
 DEPENDENCIES
 CRITICALITY
 FREQUENCY
 SCHEDULING
 RESERVE USE
 TIMING
 CONTROL

**SELECTIVE SIMPLIFICATION
 &
 COST REDUCTION**

FIGURE 10 - MEDIA ASSIGNMENT CRITERIA

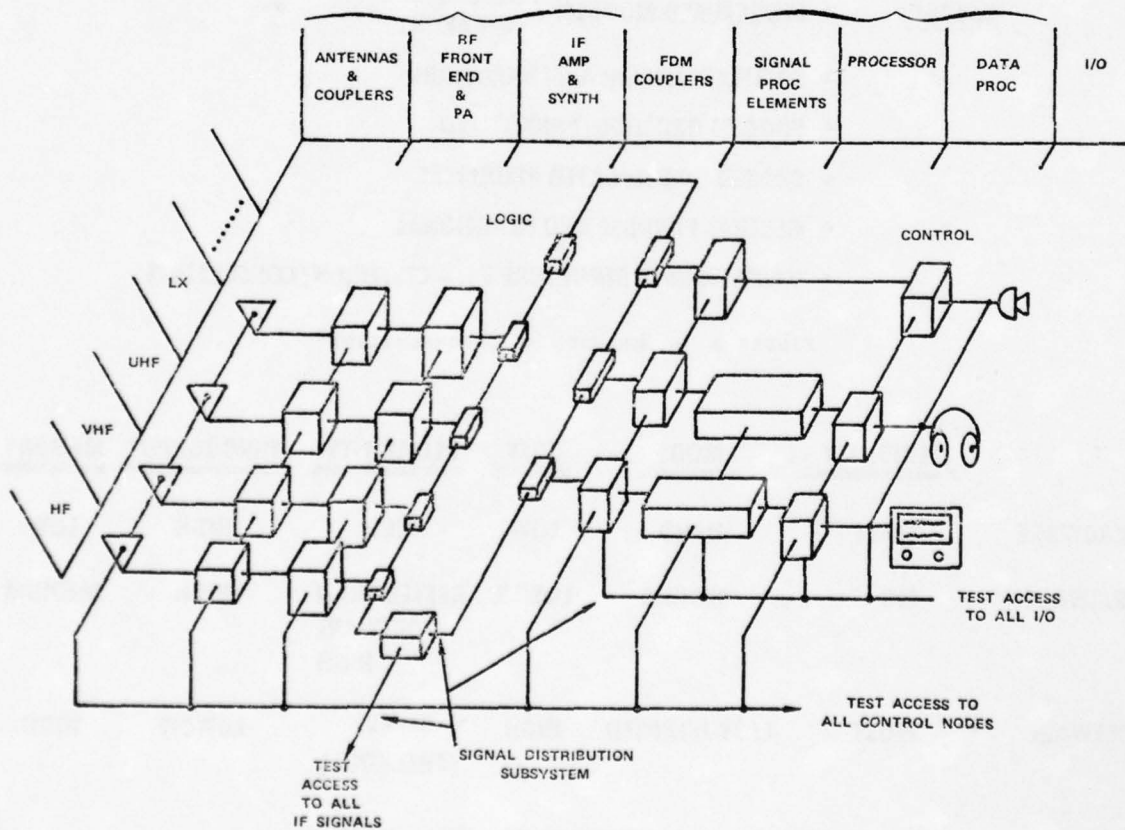


FIGURE 11 - TACTICAL INFORMATION EXCHANGE SYSTEM

- **DIRECT REPLACEMENT OF LOGIC CIRCUITRY**

USEFUL FOR LOW SPEED APPLICATIONS 1ms. RESPONSE
 REPLACES \approx 100-300 74 xx SERIES IC'S
 INCREASED FLEXIBILITY

SMALL PROGRAMS
 ALL PROGRAMS IN ROM

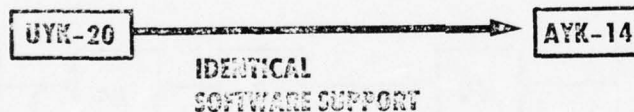
- **SMALL SCALE DIGITAL COMPUTING**

LOWER END OF MINICOMPUTER CAPABILITIES
 LOW PROCESSOR COST
 DISTRIBUTED COMPUTING SYSTEMS

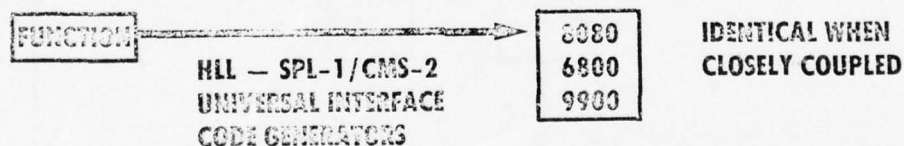
SMALL AND LARGE PROGRAMS
 LOADERS, ASSEMBLERS, COMPILERS, OS
ALL HOSTED BY MINICOMPUTER
 SYSTEMS LOGICALLY EQUIVALENT TO MINICOMPUTER SYSTEMS

FIGURE 12 - TWO MAJOR APPLICATION CLASSES

- **EXISTING COMPUTER REPLACEMENT (PROGRAMMABLE)**



- **NEW COMPUTER IMPLEMENTATION (PROGRAMMABLE)**



- **FUNCTIONAL DESIGN REPLACEMENT / IMPLEMENTATION**

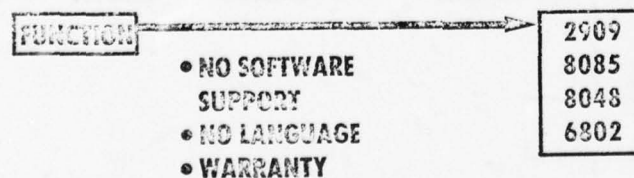


FIGURE 12A - LANGUAGE SUPPORT HIERARCHY FOR MICROPROCESSORS
 (STRUCTURED DESIGN COMPATIBILITY)

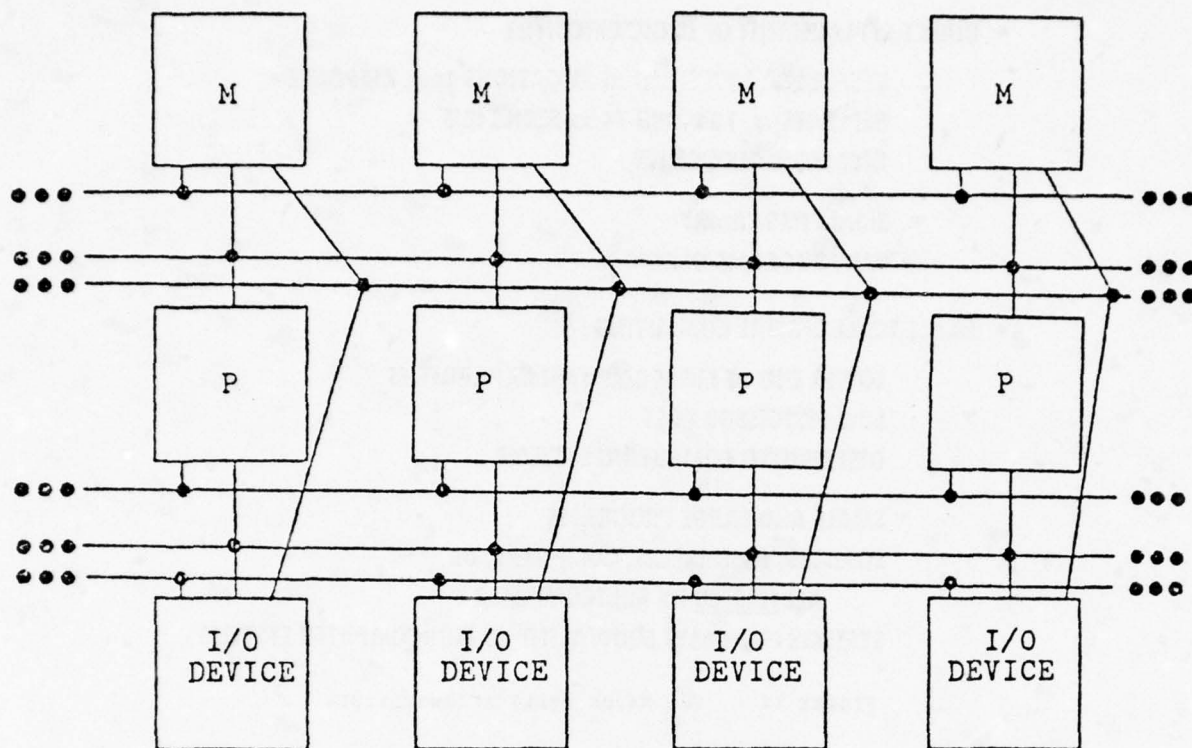


FIGURE 13 - UNIVERSAL HARDWARE STRUCTURE

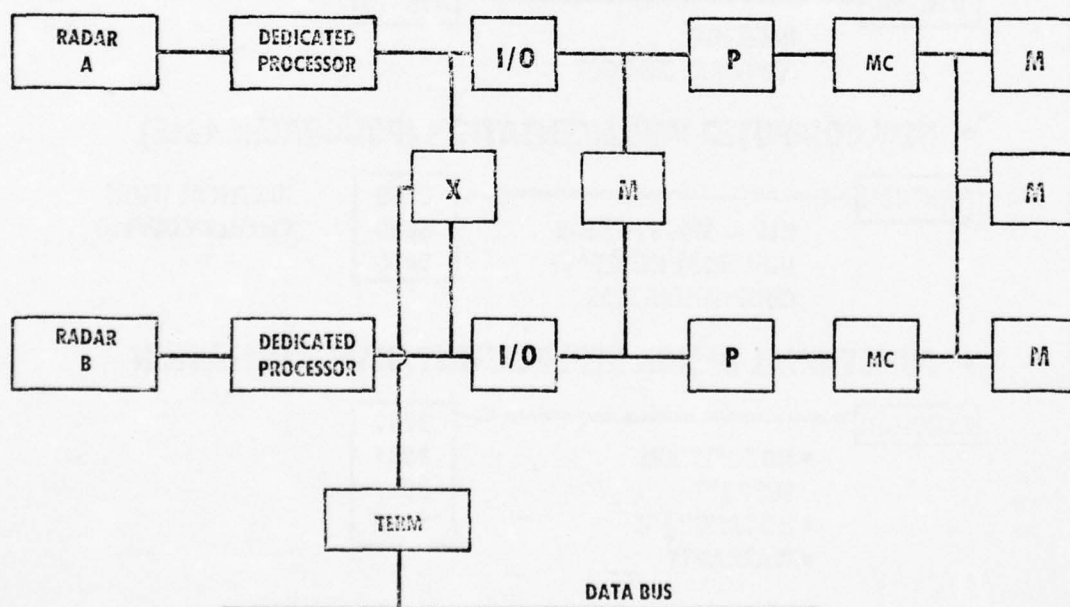


FIGURE 14 - DUAL RADAR SUBSYSTEM PROCESSING

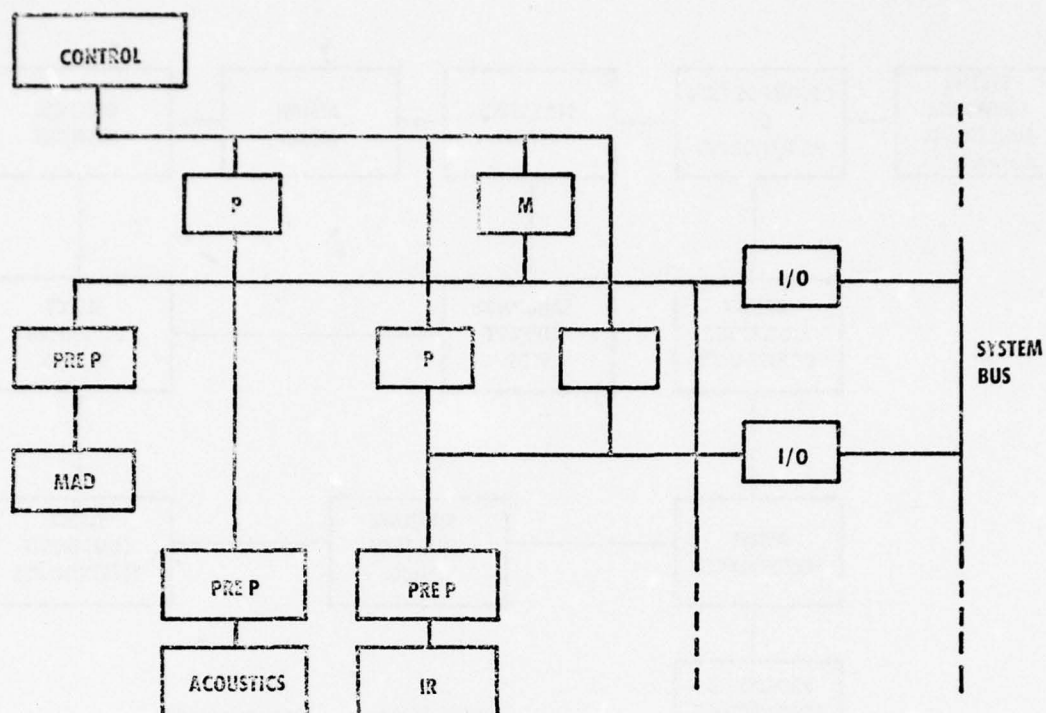


FIGURE 15 - SHARED SENSOR PROCESSING

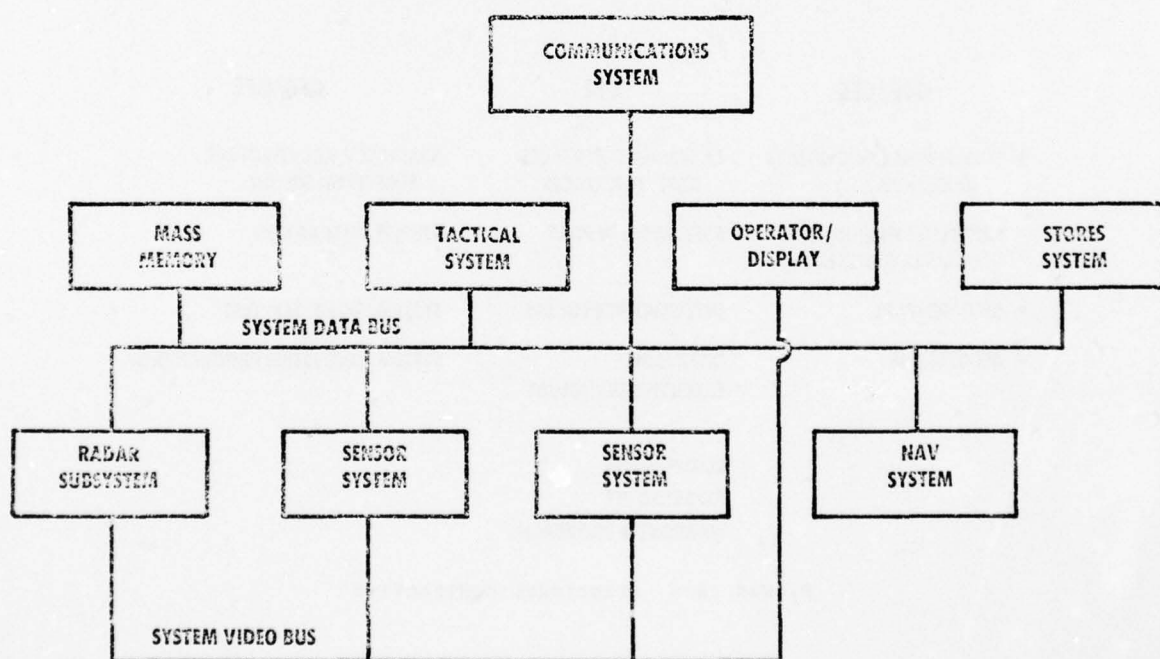


FIGURE 16 - SYSTEM NETWORK

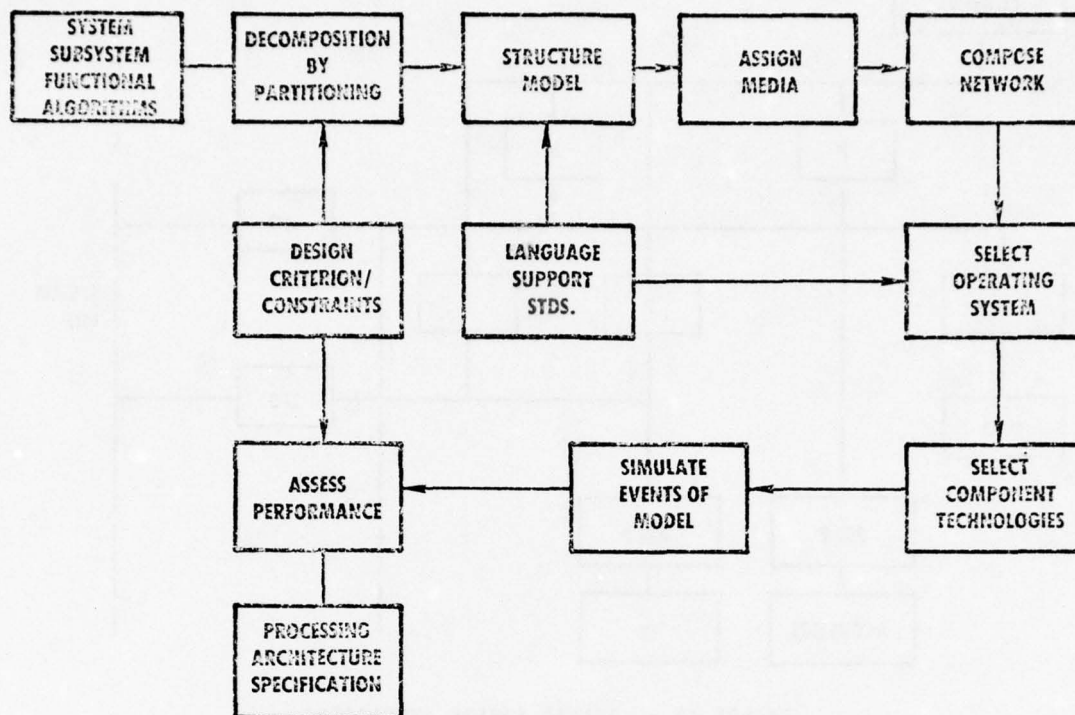


FIGURE 17 - STRUCTURED PROCESS FLOW CHART

GFE/CFE	GFE	CFE/GFE
• FUNCTIONAL COMPONENTS (ROM, HDW,)	LANGUAGE INTERFACES HDW. INTERFACES	SUBSYSTEM ARCHITECTURE SUBSYSTEM DESIGN
• LANGUAGE SUBROUTINES (MACRO, PROBLEM)	SOFTWARE SUPPORT	SYSTEM INTEGRATION
• GP HARDWARE	INTERFACE PROTOCOLS	SYSTEM/SUBSYSTEM TEST
• ALGORITHMS	DATA MGT. EXECUTIVE STRUCTURE	SYSTEM/SUBSYSTEM PROGRAMING
	COMPETATIVE AWARDED FEE WARRANTEE PROVISIONS	

FIGURE 18 - STRUCTURED CONTRACTING

DISCUSSION

J.N.Bloom

Considering the complexity of the problem, what are the requirements on management to administer such a structured process?

Author's Reply

Assuming the structured process referred to is that of avionics design with a unified data handling scheme, the management requirements are as follows:

Direct and detailed technical management of data handling interface.

Delegation by platform management of standards for interfaces (1553B), languages, software control, hardware functions.

Configuration management of functional software modules, hardware functional chips, executive control interfaces, diagnostic and BITE procedures.

Delineation of standards in subcontracts, and definition of GFE software, hardware selections.

Contract review and redirection to maintain unified objectives.

Personnel staffing with skills required for standards definition and design.

J.N.Bloom

What reporting procedures do you advocate and what reporting interval do you propose in order to avoid chaos?

Author's Reply

I would recommend a prime project staff located within 150 ft of each other with responsibility for each major subsystem and semi-monthly reviews of design, contracting, configuration, test, data, and plans for expenditures. Reporting should be to one individual (staff) for standards and configuration control of software, hardware, firmware modules, and language interfaces. Additional groups can be staffed to review performance and maintainability, test, etc.

Tactical Automated Message Processing Systems

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Summary

The automation of text message handling is a recognized requirement for both strategic and tactical command centers. Because tactical centers do not have as extensive data processing capabilities as those available at strategic centers, it has been suggested that tactical users, particularly mobile ones, should draw on the resources of large, fixed centers for some of the services requiring large amounts of computer power. This paper discusses some possible approaches to providing tactical message handling services and their effects on the design of both the tactical and strategic systems. GTE Sylvania's Communication Systems Division has analyzed the message handling requirements for both large WWMCCS command centers and small battlefield centers and has evaluated the implementation constraints of tactical systems and differences in emphasis for the various systems. If automated message handling is to meet its goal of improved writer-to-reader communications, it is imperative that both strategic and tactical systems designers consider the issues of allocation of functions and of tactical/strategic interoperability.

1.0 Introduction

Systems for providing Automated Message Processing (AMPS) are currently being designed and implemented for large, fixed military command centers. There is a clear requirement to provide this automation to deployable tactical centers as well. Since these tactical centers will interoperate with the fixed AMP facilities, it is time to consider the automation of message processing in the tactical environment. As will be seen, the capability for interoperability cannot simply be added to an existing message processing system but must be well integrated from the earliest stages of design.

The primary purpose of any AMPS is to speed writer-to-reader transit of narrative messages between command centers. The AMPS must provide assistance in message composition and coordination at the source. At the destination, messages must be routed by address and by subject, and disseminated to appropriate personnel. However, AMPS also functions as part of a "decision support system" for crisis management. Working files of messages can be maintained by subject, and the system should allow rapid retrieval, examination, and annotating of these messages at display screen consoles.

The WWMCCS architecture and related studies have described the extensive functions of AMPS as required at large fixed WWMCCS command centers. At deployable tactical centers, however, some of these functions can be done manually, some need not be done at all, and the number of messages per day may be lower. This leads to a reduced set of overall message processing requirements for the tactical system. Some of these requirements may be met by the tactical AMPS as a standalone system, and some may be provided for the tactical users by a remote, fixed site system. Whatever the mix of services provided by the fixed site for tactical users or services provided at the tactical center, it is clear that requirements such as message storage and fast response time for narrative messages imply tactical message processing capability. This paper will discuss some alternate approaches to this distributed processing problem. Factors to be considered include the tactical system hardware architecture, the constraints on the fixed site AMPS design, especially in the area of security, and the issues of system performance and interoperability.

2.0 Definition of Automated Message Processing Systems

Effective operation of command centers — both strategic and tactical — depends in part on the efficient performance of a variety of clerical details. Many of these are associated with distribution, review, coordination and preparation of narrative text message traffic. Most major centers have some degree of message center automation, usually relating to message distribution and storage; but message receipt and origination at the desk/action officer level remain essentially a manual process. A lack of automation at this level can cause delays in message handling to increase drastically with the extra message volume during crisis situations or other periods of intense activity. The effort required to handle this crisis traffic may cause cognizant personnel to be overloaded. This overload situation can result in misplaced priorities, diverted action items and unanswered or misdirected messages, to itemize only a few difficulties.

Automated Message Processing Systems are designed to extend the automation now provided by communications centers and message networks to the command centers and so to alleviate the overload situation as well as to provide an increase in message center efficiency during normal operation.

The major capabilities to be provided by an automated message processing system are as follows:

- Support the receipt, indexing, storage, and distribution of incoming text/narrative messages.
- Provide on-line capabilities to retrieve, review and manipulate stored text messages.
- Support the preparation and transmission of operation orders, outgoing directives, and other text messages, as required.
- Provide direct terminal support to desk officers, action officers, and other internal command center staff members for activities associated with text message handling.

These major capabilities are required for an AMPS at any command center, whether strategic or tactical, fixed or deployable. However, the specific requirements for a particular system will vary depending on mission characteristics, the amount of message traffic, types of message sources and destinations, the sophistication of the decision support provided, the degree of interoperability with other systems and the level of communications support required. These requirements must be evaluated on a site by site (or mission) basis.

In general, however, because of the above considerations, the functional requirements for a tactical AMPS will be a subset of WWMCCS fixed site requirements. The WWMCCS approach to AMPS will therefore be examined first. It should be noted, in addition, that significant portions of the design and some lesser amount of the software for Automated Message Processing Systems at tactical command centers can likely be derived from the WWMCCS fixed site approach. Additionally, the WWMCCS Transition Plan follows this observation by suggesting that the deployable AMPS act as a remote terminal of the fixed site and use the larger system for additional processing and message storage.

2.1 WWMCCS Message Processing System — Operational Concept

The WWMCCS Transition Plan includes an operational concept for Automatic Message Processing Systems at WWMCCS Command Centers. Messages reach the Command Center via an assortment of communication systems. Once a message has arrived, the AMPS will write a journal entry on a message log, assign message identification codes, store the message for on-line recall, and automatically distribute each message to the appropriate recipient. A Master Message Terminal operator oversees and coordinates distribution and acts as a default message queue for all messages which do not match any user-interest text profile. Special handling is provided for high precedence and other designated message types.

Messages are queued by precedence and date-time-group at each CRT terminal, and users will be notified of their arrival. The users can view the message on request, and can override the AMPS generated queue to view messages in any desired order. In addition, the system will permit the user (in this case a message recipient) to:

- a. Edit and annotate the messages;
- b. Store the original (or modified) message in either a data base file (e.g., crisis file) or in a private user file;
- c. Route the original (or modified) message to other terminals;
- d. Initiate a conference with other terminals on the contents of the message;
- e. Hold the message in his queue pending further action, and
- f. Purge the message from his queue.

The user can recall messages by date-time-group, originator reference code, subject, disseminator, etc. Once he has retrieved a message, he can perform any of the above operations on it.

When the AMPS user is using the system to facilitate message composition, release and transmission, the AMPS provides a file of preformatted message forms and messages, and it will assist the operator in message header assembly and in assignment of addressees, precedence, and security codes. "Cut-and-paste" editing capabilities will allow recalled references and messages, or parts of these, to be incorporated in a new message as it is being composed.

Draft messages can be stored and routed to other terminals for coordination, authorization, and release. After completion of this process, the system will transmit the message to the telecommunications center for output, and receive a positive indication from the message center of message receipt.

In addition to the operational capabilities, the AMPS will also provide for informal interuser memos, user conferences, on-line modification of user profiles, and training and exercise support.

Table 1 summarizes the major AMPS functional requirements for fixed WWMCCS-like command centers. The table clearly shows the distinction between a message processing system and a message switch or communications center. The WWMCCS AMPS complements an automated telecommunications capability, but does not provide it.

Table 1
AMP Major Functions and Derivative Capability Objectives (Ref. 1)

<ul style="list-style-type: none"> • Telecommunications Center Interface <ul style="list-style-type: none"> — Acknowledge notification — Journal, log — Precedence/DTG Queuing — Misroute intercept • Message Distribution <ul style="list-style-type: none"> — Automated distribution based on message profile (e.g., subject, "for" indicator, references) — Dissemination review at master message terminal for semiautomatic, "ad hoc" routing — Addressee-arranged precedence queues — Incoming message notices (e.g., audio/visual alarms) • Message Storage <ul style="list-style-type: none"> — Storage of original/modified copy — Subject index insertion for correlation recall — Move messages from/among files 	<ul style="list-style-type: none"> • Message Retrieval <ul style="list-style-type: none"> — Message/data menus — Recall by specified subject — System notices (e.g., retrieval/query errors, additional information required to process query) • Message Composition/Transmission <ul style="list-style-type: none"> — Fill-in-the-blanks forms — Assembly of message headers — Semi-automated address-see, precedence, security assignment — Text edit capabilities — Handoff for coordination, authentication, release — Come-back copy posting • Security <ul style="list-style-type: none"> — Prevent unauthorized disclosure — Prevent unauthorized transmission — Security/privacy indicators — Authorization control 	<ul style="list-style-type: none"> • User-Oriented Features <ul style="list-style-type: none"> — Shift log — Crisis log — Action/information message log — Private working files — Historical files — Reference files — Pending action queue — Hold queue — Console-to-console communications — Multi-terminal conferencing — System notices — Automated assistance — Dynamic message profile modification • Exercise Support <ul style="list-style-type: none"> — Parallel real-exercise modes (by terminal) — Simulated incoming message and prestored data generation • Statistics Gathering <ul style="list-style-type: none"> — In/out traffic volume — "In-house" transaction elapsed time — Query/response elapsed time — System failures/down time
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2.2 WWMCCS AMPS Processing Requirements

As part of a technical analysis and cost estimate (TA/CE) for implementing automated text message handling at the Pacific Fleet Command Center in Hawaii, GTE Sylvania estimated the amount of ADP support required for a standalone automated message processing system. Standalone, in this context, means that no other existing ADP facilities were adapted for use in the AMP. The TA/CE concentrated on a standalone system because of the severe disruption to existing system capabilities if they were modified to support distributed AMP. It should be noted that that study's results are very site dependent as regards possible implementation. Because the Pacific FCC AMPS is a standalone design, however, much can be gleaned from it concerning WWMCCS AMPS processing requirements.

Our TA/CE estimates assumed that telecommunications support would be provided by an LDMX installation, that there would be 16 AMPS user terminals, and that the crisis message load would approximate 2400 messages per day. The WWMCCS AMPS concept requires 5-day message storage or about 800×10^6 bits. The response time requirements are shown in Table 2.

With these requirements we calculated that two Digital Equipment Corporation PDP-11/70s could provide the required processing power. The reliability of such a configuration is much less than the .9995 recommended by the WWMCCS Transition Plan since the processors are not redundant. GTE Sylvania's recommended configuration includes the two processors, each with 218,000 words of memory, three dual access disks (one controller) with a total of 132 million words of on-line storage, three

nine-track magnetic tape units, line printer, card readers, and intelligent high speed CRT terminals. Even with this large computer installation, there is not sufficient capacity for redundant message storage nor is there a back-up processor for added reliability.

We did not include a redundant processor because of cost considerations and because of the large amount of message related ADP equipment on site. Some back-up processing could be provided by this other equipment in an emergency although not with all of the AMPS functions or coherence. Thus, our estimates agree very closely with the WWMCCS prediction that a four processor system would be required for reliable automatic message processing at a WWMCCS fixed site.

Table 2
WWMCCS AMPS Response Time Requirements

Capability	Performance (In Seconds)
a. Input message receipt to desk/action officer notification	60
b. Retrieve and display a user selected message	2
c. Delivery of FLASH or higher message to desk/action officer	10
d. Retrieve and display a previously stored display from data base	3
e. Acknowledge a user keyboard action	2
f. Route a display/message from one user terminal to another	5
g. Transmit an outgoing message	60
h. Produce hardcopy output from a single screen	15

3.0 Tactical Message Processing

This section will discuss the major requirements for an automated message processing system in a tactical environment. Possible allocations of these requirements among tactical and fixed site systems will be discussed in terms of distribution of functions and interoperability.

3.1 Tactical Message Processing Functional Requirements

Because of operational differences, arising out of mission characteristics, between a large WWMCCS-type command center and a deployable tactical installation and the fact that the tactical center can rely on the fixed center to some extent, a smaller ADP implementation can probably meet all of the tactical message processing requirements.

The major impact on the WWMCCS AMPS comes from the number of messages processed per day, the number of terminals which must be supported, and the elaborate message profiles needed for efficient management of complex situations. The tactical AMPS is a smaller and less complex system. Table 3 shows a comparison of strategic and tactical system design goals.

Table 3
Comparison of Strategic and Tactical System Design Goals

	WWMCCS Center	Tactical Center
• Traffic load	2400 msgs/day — crisis	500-2400 msgs/day — crisis
• Terminals supported	12-16	3-4
• Messages stored	5 days	24 hours
• Message distribution by	key words user profile	subject line message type
• Communications interfaces/formats	many	fewer
• Exercise support capability	required	optional
• Handoff for coordination	required	informal
• Message generation support	canned formats, editing	canned formats, editing
• Security	multilevel, intelligence	multilevel or system high

3.2 Tactical Message Processing System Operation

From Table 3 it can be seen that the message processing requirements at a tactical command center are substantially less than those required at a large WWMCCS center. The current state of the art allows the tactical AMP to operate in either a standalone mode or in a distributed processing configuration.

In a distributed processing configuration the tactical AMPS would rely on a WWMCCS fixed site for support in message storage, message distribution, exercise support and communications interfaces. Note that it is likely that tactical AMPS will have sufficiently narrow missions to preclude a universal

implementation. This, in turn, implies the design of a WWMCCS command center which may have to support several different tactical AMPS. The WWMCCS Transition Plan assumes that deployable AMPS will operate as a distributed system, in some cases as remote terminals. We will explore some further implications of this approach in Section 3.5.

The recent availability of large minicomputers for military use, notably the Norden version of the DEC PDP 11/70 may lessen the tactical/strategic interoperability problem by providing the means for a standalone version of a tactical AMPS.

3.3 Independent Tactical Message Processing System

With the reduced tactical AMP requirements, it is clearly possible to design a totally standalone AMPS for tactical use. This independent system would maintain its own message data bases, perform all of its own processing and format messages as required for any interfacing network, etc. The interface to other command centers would be through the communications center by means of narrative messages or an AUTODIN Query/Response type capability. Because there is no interface with other AMPS except via messages and because these messages are directed from one person to another and are not automatically processed, this standalone AMPS has minimal interoperability requirements. In fact, the only requirements are interoperability of the communications systems and compatible message formats. If simplicity of implementation and straightforward achievement of interoperability are the primary design requirements, then a standalone system is clearly the best choice.

An independent tactical AMPS has major additional advantages if the WWMCCS fixed site version adopts the DEC PDP-11/70 processor (as seems likely). A tactical system could then use the NORDEN PDP-11/70M militarized version, which is entirely software compatible. The use of fixed-site software would probably greatly reduce the development cost and schedule of tactical AMP and allow earlier extension of this capability to the tactical world.

3.4 Arguments for Distributed System

The major arguments against a fully capable, independent AMPS are, of course, the resources required, especially those of space and power. Message processing is not the only, nor in fact the major function of a tactical command center, and the allocation of two large midicomputers with full complements of peripheral equipment is one which would require substantial justification. While a standalone system may be optimal from an implementation and performance viewpoint, it is probably not the best choice for any but the largest tactical sites.

A further argument against using the available ADP resources for standalone AMPS lies in the need for integrating command center C³ operations. At the WWMCCS command centers, there are separate ADP systems provided for Communications (LDMX, AMME, etc.), General data processing (WWMCCS ADP), intelligence data processing, and Automated Message Processing. Generally, each of these systems has separate staffing, terminals, etc. and they all have separate processor configurations. The systems communicate with each other via data links of various speeds, but in distributed processing terms, the command center is a very loosely coupled system. Efforts are currently underway to integrate some of the command center functions to provide the staff with a more complete view of the situation. However, restrictions on data access require a solution to the multilevel security problem before more than token integration is possible.

In a tactical center, the smaller staff, more unified mission, and space and power constraints all increase the need for an integrated C³ system. In fact, if automating the message handling and communications functions results in an increase in the amount of information which must be acted on by staff personnel, this will also result in an increase of the effort required for analysis and evaluation of the communicated information at the tactical center. If some of the less mission-critical information and message processing can be offloaded from the tactical command center to a remote fixed site, then more ADP resources can be directed towards the needed data analysis and the tactical system can provide real decision and management support to the battle itself.

3.5 Distributed Processing Impacts

A distributed AMPS concept envisions the tactical AMPS as a sophisticated remote terminal to a fixed system, with the tactical AMPS strongly committed to decision and management support. This concept implies that each tactical AMPS would rely on the fixed site for a large part of the more "mundane" AMPS processing such as message distribution, message storage and retrieval. As previously noted, it is likely that tactical AMPS will have sufficiently narrow missions that will preclude universal implementation.

There is a strong implication in this observation that the design of a WWMCCS command center must support several tactical AMPS in a dynamic manner. In addition, our research for the Pacific FCC showed that distributing a message processing system among loosely coupled processors increases system response time by a factor ranging from two to three depending on configuration. One could expect, then, not only the tactical AMPS response to be lessened but also to expect the fixed site processing to degrade, especially if more than one tactical AMPS draws on it for support.

To date, there is little evidence that the interoperability problems arising from the concept of distributed message processing have been given the attention or emphasis they deserve. There are at least three major interoperability considerations that must be addressed:

First, there is a security problem introduced by the fact that the security level of the deployable command center is unlikely to be the same as that of the fixed center acting as host site. Note that if the entire deployable system is at a single security level, then it does not require multilevel security; it is the responsibility of the host site to provide the security protection in this case. This separation of levels may pose a major problem for fixed-site AMP and may require either full multilevel security, a filtering interface processor, or some other security mechanism.

A second interoperability/security problem is introduced if the deployable "remote terminals" access fixed AMPS facilities via the AUTODIN communications network. Fixed site AMP terminals are presumably on-site and hardwired so that only nominal terminal authentication procedures are necessary. For remote access via DSCS satellite, or other means through the network, it is clearly necessary to completely authenticate any connection and all requests for access to the data base.

The last interoperability consideration addressed here is the insurance of increased writer-to-reader speed of service, which is, after all, the major goal of automated message processing. As our analysis has shown, distributing functions between deployable and fixed sites introduces significant increases in response times. Candidate existing systems and adaptations thereof must be carefully analyzed and designed to insure that the speed advantages provided by automation are not outweighed by the delays caused by the need for multiple exchanges between the host and deployable systems. Both the message handling procedures and the speed-of-service provided by the communications network enter into this performance analysis.

It must seriously be questioned, then, whether a distributed AMPS can be justified in terms of either performance or capability.

Conclusion

The degree to which automated message processing can be provided for deployable tactical centers depends on the level of capability to be provided and a resolution of the interoperability/security problems between fixed WWMCCS command centers and deployable tactical centers.

Although a distributed tactical AMPS capability is desirable from several viewpoints, an implementation of this concept must be reserved for the long term pending an assessment and resolution of the interoperability and security issues discussed in this paper.

For the near term, deployable tactical centers must rely on standalone systems for automated message processing. While the NORDEN-11/70M can provide full tactical AMP capability if necessary, it is by no means clear that a full capability is always necessary or desirable. For these situations a subset of the full tactical AMP capability must be developed.

References

1. GTE Sylvania, CSD, "Technical Analysis and Cost Estimate for an Automated Text Message Handling System at CINCPACFLT Headquarters", 10 October 1977.
2. Annex F, WWMCCS Transition Plan
3. Dr. H.J. Tiller, C³ Automation for the CTOC Approach, GTE Sylvania, CSD, 19 January 1978.

DISCUSSION

A. Clearwaters

You indicated that one of the major problems with a distributed system is that, in times of stress, system services will change to loading. Since dedicated systems must also exchange messages and it is clear that the message traffic will increase dramatically during stressful times, won't dedicated systems experience the same kind of problems you ascribe to a dedicated approach?

Author's Reply

It is true that the message traffic will increase in a crisis, and this is independent of the system design. However, because of traffic load or a breakdown in the specific communications path between a tactical AMP and its host system, the actual functionality of the system may change (degrade) during a crisis. This qualitative change and elimination of some system capability presents, I think, a far more serious operational problem than just the extended response times caused by heavy message traffic.

I. Mirman

As I understand it, key words are used to index messages for retrieval. Do you think it possible to classify messages in terms of importance, change, redundancy, surprise, etc.?

Author's Reply

The key word retrieval capability now attainable can certainly be used to classify messages for such things as relevance to a situation, timeliness, explicitly stated precedence, addressee's name, etc. The intent of the AMP system is to allow the command center staff to select a profile of interest parameters and to change this profile as the situation evolves. If the parameters of change, redundancy and surprise could be precisely described in terms of message content or header information, these parameters could be used as well. However the exact description of these is, I believe, beyond the capability of current system users and designers.

TERMINAL DE COMMUNICATIONS TACTIQUES D'INFORMATIONS ALPHANUMERIQUES

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1 - INTRODUCTION

Le terminal faisant l'objet de cette communication s'intègre dans le système ATILA (Automatisation des Tirs et des liaisons de l'Artillerie). Il a été développé sous la responsabilité de la DTAT/Section d'Etudes et de Fabrications des Télécommunications (DTAT/SEFT). Sur le plan des objectifs, le terminal participe aux quatre concepts :

1.1 - Aide à l'automatisation du feu

Le terminal possède un ou plusieurs postes de dialogue (Ecran + Clavier alphanumérique). L'opérateur, chargé des tirs, travaille sur des grilles (Figure 1) dont le format a été étudié pour minimiser les erreurs humaines, réduire le temps de formation et accroître la rapidité des prises de décisions.

Le terminal retransmet automatiquement les paramètres de tir destinés aux pièces d'artillerie (à chaque pièce, un système de téléaffichage à haute sécurité de visualisation permet d'afficher ces paramètres).

1.2 - Réseau de transmissions de données

Les différents intéressés (officiers du commandement, officiers de tir) du champ de bataille échangent leurs informations par l'intermédiaire des postes de dialogue et sont abonnés à un réseau de transmissions radio hiérarchisé. Le terminal réalise chacun des centres nœuds du réseau et assure :

- une transmission automatique des messages,
- une affectation rapide de l'information entre les divers abonnés,
- une sécurité dans l'acheminement de l'information,
- une amélioration des temps de réponse de la chaîne d'artillerie,
- un acheminement adaptatif du message en cas de perturbations locales du réseau (ou retour à l'origine).

1.3 - Aide au commandement

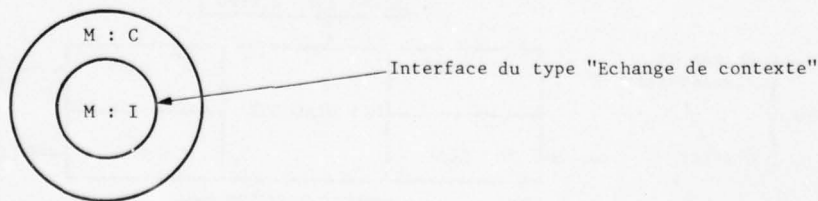
Le commandement, abonné au réseau, en est l'animateur principal. Il dispose pour cela d'un calculateur qui met à sa disposition l'ensemble des informations nécessaires au suivi de l'évolution du champ de bataille (Base de données). Dans ce cas, le terminal joue le rôle d'un terminal lourd de visualisation et assure la collecte et l'acheminement de toutes les informations nécessaires à la chaîne d'artillerie.

1.4 - Adaptations à différents besoins

Le terminal est programmable. Sa structure lui permet donc de s'adapter selon les besoins à des systèmes en mode réseau centralisé ou décentralisé (Figures 2a et 2b). Le passage d'un système à un autre est semi-dynamique (inférieur à une heure). La structure du système ATILA centralisé est donnée figure 2c.

2 - STRUCTURE SYSTEME DU TERMINAL

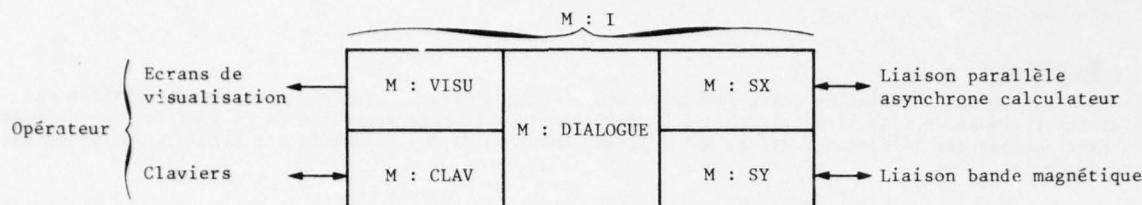
Sur le plan de la structure système, le terminal peut être considéré comme une machine "Interface opérateur" (M : I) associée à une machine de commutation (M : C). Globalement, la structure se présente sous la forme "Image" suivante :



2.1 - Description de la machine M:I

Cette machine permet le dialogue de l'opérateur avec l'environnement externe. Dans le cadre du terminal, les moyens de dialogue de l'opérateur sont des écrans de visualisation et des claviers. La relation avec le "puits de données" se fait par l'intermédiaire :

- d'une liaison parallèle asynchrone (Machine M : SX) pour le terminal relié au calculateur (variante correspondant au commandement),
- d'une liaison bande magnétique (Machine M : SY) pour le terminal autonome (variante correspondant aux batterie et détachement de liaison).



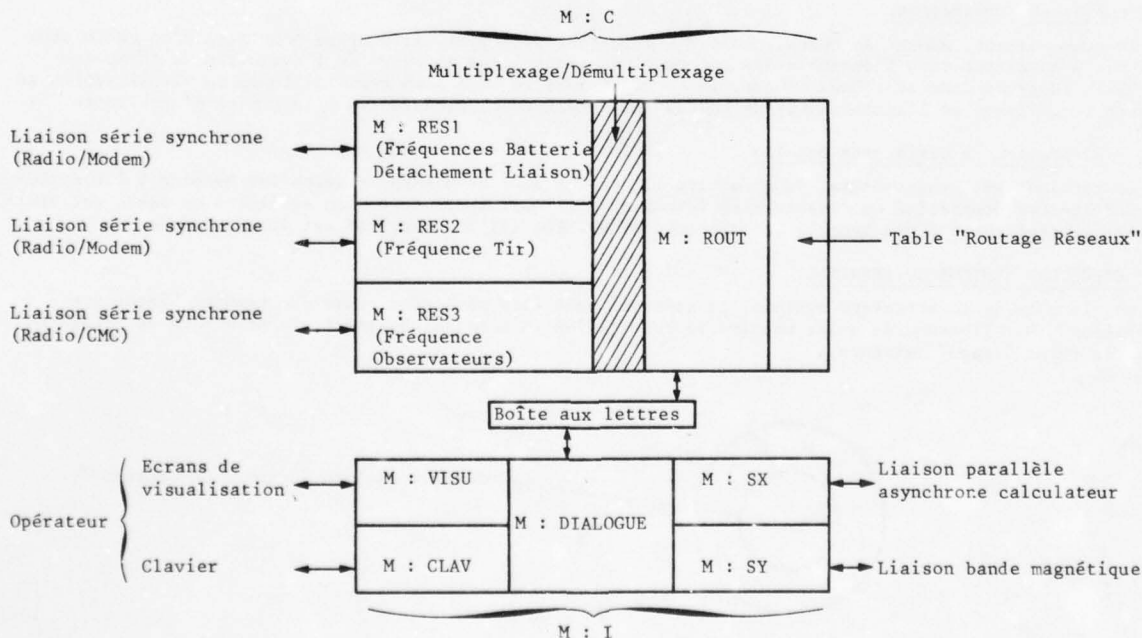
2.2 - Description de la machine M:C

Cette machine permet les échanges d'informations sur le réseau et le relai de ces informations. Elle se décompose en :

- machine M : RES (Machine "Réseau") permettant l'émission et la réception des informations de façon synchrone. Au plus, il existe 3 machines, l'affectation des fréquences correspondantes est fonction de l'utilisation du terminal,
- machine M : ROUT (Machine "Routage") permettant, soit le transfert d'informations sur le réseau, soit le relai des messages. Cette machine assure le multiplexage et le démultiplexage des informations si cela est nécessaire.

Pour assurer son travail, cette machine exploite des tables de routage du réseau qu'elle met à jour elle-même à chaque intervention qu'elle effectue sur le réseau, ou sont mises à jour périodiquement par des messages spécialisés traités de façon particulière.

La machine M : C est microprogrammée et macroprogrammée (gestion du réseau). Les échanges avec la machine M : I se font par "Echange de contexte" du type "Boîte aux lettres".



Pour les machines M : SX, M : RES1 et M : RES2, le protocole de transport des informations est en mode "Paquet", pour la machine M : RES3 en mode "Message".

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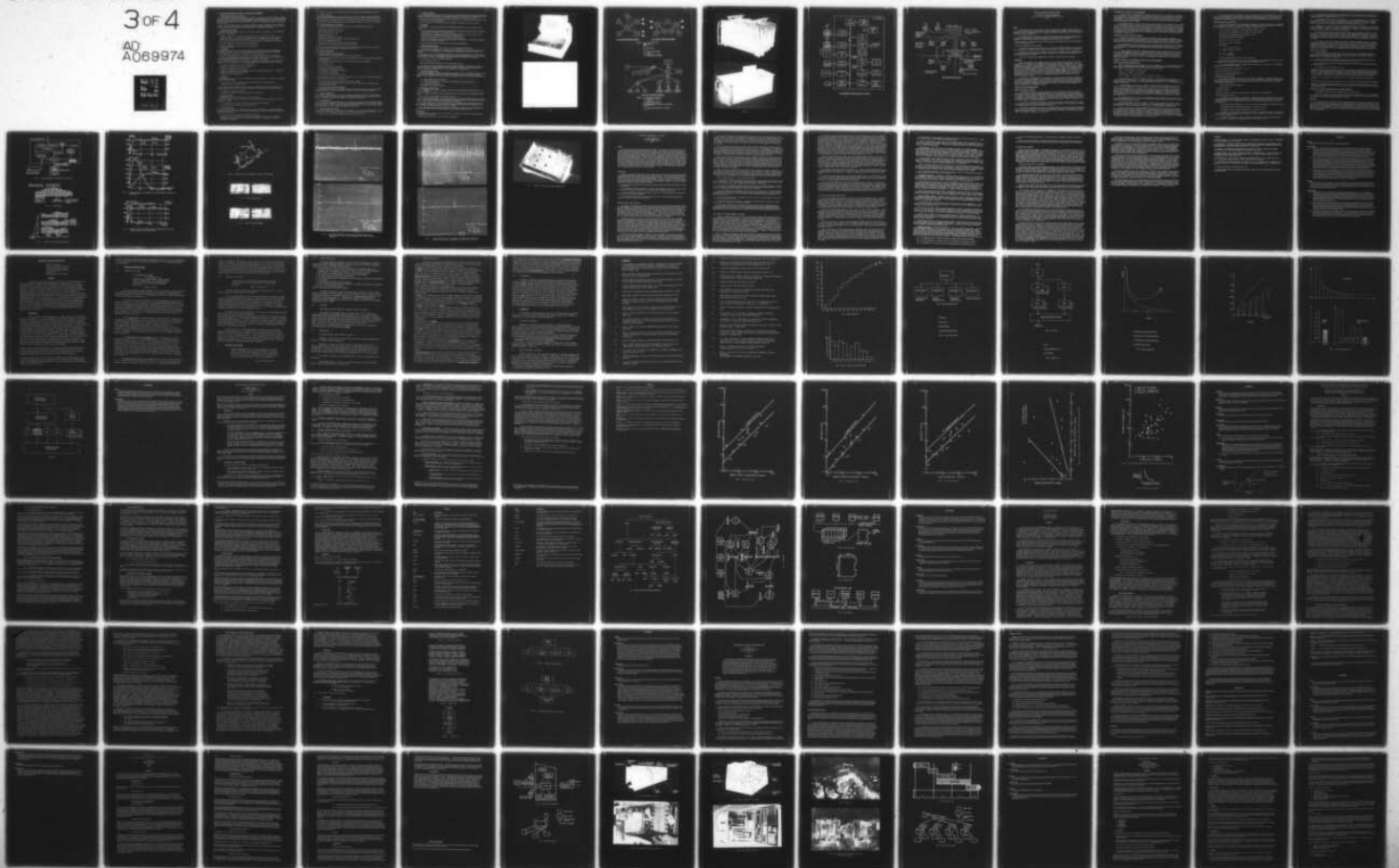
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3 - ORGANISATION FONCTIONNELLE DU TERMINAL - CONDITIONS D'ENVIRONNEMENT

3.1 - Organisation fonctionnelle du terminal

La figure 4 donne l'organisation fonctionnelle du terminal. Ce terminal est réalisé à partir d'un microprocesseur rapide utilisant les plus récents développements technologiques (Circuits de la famille AMD 2900). Son temps de micro-instruction est de 300 nanosecondes. Le coupleur minibande est construit autour d'un LSI MC 6800 ; il peut effectuer des sauts et recherches de fichiers. Le microprocesseur central peut supporter de 1 à 4 écrans.

Enfin, il est intéressant de noter les volumes de programme (4 K mots en mémoire morte pour le micro-logiciel, 4 K mots en mémoire banale pour le macrologiciel, 8 K restant à la disposition de l'utilisateur). Ce dernier point montre l'intérêt de la solution par rapport à une solution calculateur.

3.2 - Conditions d'environnement

Le terminal est conçu pour être installé sur véhicule tout terrain ; le matériel est donc réalisé pour satisfaire à l'environnement :

- mécanique (vibrations 5 g de 10 à 500 Hz ; secousses 25 g, 6 ms ; chocs 30 g, 11 ms),
- climatique (- 25°C ; + 55°C ; 40°C 95 % d'humidité relative ; stockage - 40°C, + 70°C, brouillard salin). Pour améliorer la dissipation thermique, les cartes sont équipées d'un bus thermique,
- perturbations radioélectriques (conduction et rayonnement MAT 7291 ; susceptibilité MIL STD 462).

Deux types d'intégration des matériels sont présentés figure 3.

4 - LE LOGICIEL DU TERMINAL (la figure 5 donne son architecture)

4.1 - Présentation

Le logiciel, construit autour d'un moniteur temps réel, se compose d'une partie microprogrammée implantée dans la mémoire morte et d'une partie macroprogrammée située dans la mémoire vive banale.

Le microprogramme est exécuté par le microprocesseur (micro-instructions).

Les instructions macroprogrammées (primitives) sont interprétées par le logiciel microprogrammé.

Le logiciel macroprogrammé est lui-même constitué d'un logiciel système livré avec le terminal et d'un logiciel macroprogrammé spécifique à l'application à la charge de l'utilisation.

Le macrologiciel système peut exister en plusieurs versions qui seront chargées à l'initialisation du terminal, soit par le calculateur, soit par la bande magnétique pour le terminal autonome. Il assure :

- la gestion des transferts sur le canal Bande Magnétique,
- la gestion des échanges sur le canal calculateur,
- la gestion des messages CMC (observateurs),
- la gestion du graphe des réseaux de transmissions (deux fréquences simultanées) et le formatage des messages et le déclenchement des transferts,
- l'initialisation des tâches système.

4.2 - Primitives

Le macroprogramme est écrit à partir d'un langage constitué de primitives ou instructions qui possèdent les deux propriétés suivantes :

- l'instruction peut avoir plusieurs adresses d'opérandes (machine à plusieurs adresses),
- l'instruction est de longueur variable.

Outre les instructions du moniteur, de gestion des files en mémoire de travail et de calculs, le terminal possède deux familles d'instructions qui permettent de traiter avec une très grande souplesse :

- la gestion de la visualisation (écrans),
- les transferts (contrôles du réseau sous procédure de transmission).

4.3 - Gestions des écrans

Ce paragraphe montre l'intérêt des instructions de visualisation.

Le logiciel du terminal réalise la création ou la modification dynamique des éléments de la liste de visualisation à partir :

- soit des résultats et des ordres fournis par le macroprogramme d'application,
- soit des informations fournies par l'opérateur (clavier).

4.3.1 - Gestion de l'écran

L'écran est structuré en zones (16 maximum) gérées de façon indépendante (on a donc l'équivalent de 16 écrans). Dans chaque zone sont présentées des informations sous la forme de chaînes de caractères qui peuvent être de deux types :

- des textes invariables protégés non accessibles à l'opérateur,
- des variables qui sont des champs de caractères modifiables par l'opérateur ou le programme d'application. Dans certains cas, elles peuvent être protégées par le programme et ne sont plus accessibles à l'opérateur.

Les chaînes de caractères sont rassemblées en grille qui peuvent être affichées dans les zones.

4.3.2 - Gestion des zones

Les zones sont rectangulaires et, à un instant donné, le guide de frappe de l'opérateur ne peut se trouver que dans une seule zone et ne peut en sortir que par action du macroprogramme d'application.

Dans chaque zone, le programme d'application a la possibilité d'introduire une grille et une seule.

Les zones sont définies en dynamique par le macroprogramme d'application au moyen d'une primitive.

4.3.3 - Actions entreprises sur les images

Les actions sont développées à partir des instructions du macroprogramme d'application :

- visualisation d'une grille dans une zone,
- mise à jour des variables de la zone,
- envoi des variables d'une zone,
- effacement d'une zone,
- effacement des variables d'une zone,
- modifications des attributs relatifs à des variables d'une zone,
- tests sur les variables d'une zone,
- visualisation d'une chaîne de caractères dans une variable,
- gestion d'un pointeur d'exploration des variables d'une zone.

Les instructions de visualisation confèrent donc à l'opérateur du terminal autonome, en dehors de toute connexion à un ordinateur, des traitements puissants d'image.

5 - GESTION DES TRANSMISSIONS

5.1 - Présentation du logiciel correspondant

Le logiciel "Gestion des Transmissions" est réalisé en deux parties :

- microprogrammée (en mémoire morte) banalisée et indépendante du déploiement des terminaux en réseau centralisé ou non,
- macroprogrammée système spécifique à l'utilisation du terminal (PC, DL, BATTERIE).

Le microprogramme traite :

- la gestion d'émission dans les phases,
- la synchronisation émission/réception,
- les compactage et décompactage des messages,
- la reconstitution des messages,
- la validité d'un message (structure, CRC).

Le macroprogramme travaille sous contrôle du moniteur et est donc libéré des problèmes de temps réel.

Les deux fonctions essentielles assurées sont :

- la fonction gestion du réseau et mémorisation de l'état du réseau,
- la fonction relayage (aiguillage, fonction réalisée à partir des informations stockées par la fonction gestion du réseau).

5.2 - Principes de la procédure de transmission

La procédure employée a pour but d'éviter les risques d'interférence en dépit de l'utilisation d'une fréquence commune, tout en assurant un maximum de discrétion en ce qui concerne les émissions.

5.2.1 - Type de transmission

Les échanges entre les abonnés sont du type multiplexage temporel et permettent la liaison entre un maître et un ou plusieurs esclaves (par exemple en réseau centralisé PC → B ; en réseau décentralisé DL → B). Le temps d'un échange entre un maître et un esclave est appelé phase.

5.2.2 - Notion de relais

En cas de mauvaise propagation empêchant la liaison directe, un abonné esclave peut prendre le relais d'un abonné maître. L'abonné relais se substitue à l'abonné maître pour établir la liaison avec l'abonné relayé. Un message, émis par le maître pour l'abonné relayé dans le créneau de temps d'un abonné relais, sera réémis par celui-ci dans le créneau de temps de l'abonné relayé.

5.2.3 - Notion de maître et d'esclave

Vis-à-vis d'une liaison, il existe toujours un abonné maître, c'est-à-dire libre d'émettre le premier dans la phase, l'autre abonné est esclave car il ne peut émettre que si le maître ne dit rien.

En liaison relais, l'abonné maître délègue ses pouvoirs à un abonné relais.

5.2.4 - Notion de message

Les messages opérationnels transitant dans le réseau sont précédés d'un préambule de service permettant au maître de donner des directives et à l'esclave de retourner des informations. Ces messages peuvent être découpés en paquets, chaque paquet étant accompagné de ses propres informations de contrôle.

Par ailleurs, pour des raisons de saturation et de discrétion, un message correctement reçu peut ne pas faire l'objet d'un accusé de réception.

Enfin, un message de service particulier permet d'assurer un contrôle de flux sur le réseau.

6 - MAINTENANCE

Le terminal est conçu pour satisfaire à une politique de maintenance dont les objectifs sont les suivants :

- temps d'indisponibilité opérationnelle limité (découpage en sous-ensembles pouvant être isolés pour la recherche de la panne) à une demi-heure maximum,
- automatisation de la recherche de la fonction en panne à l'intérieur d'un sous-ensemble (ce qui impose des fonctions enfichables) ainsi que de la réhabilitation,
- automatisation du contrôle des lots de rechanges (déstockage rapide),
- conception des plaquettes à circuits imprimés enfichables orientée pour la recherche du composant en panne avec l'aide d'un banc universel.

Ces trois derniers points sont traités en dehors du contexte opérationnel.

6.1 - Maintenance premier niveau

Ce niveau permet à l'opérateur de s'assurer du bon fonctionnement de son terminal.

Le terminal possède en mémoire morte un micrologiciel de maintenance qui permet de s'assurer du fonctionnement global du microprocesseur, de la mémoire morte, des mémoires vives à l'initialisation du terminal.

En transparence avec le fonctionnement opérationnel, le microprocesseur surveille le fonctionnement du bus (séquençement, données) et des coupleurs (mot d'état, validité des informations). La carte système par sa surveillance du matériel, indépendamment du microprocesseur, peut suppléer à sa défaillance.

Les résultats sont transmis sous forme synthétique :

- soit à un panneau centralisé,
- soit par un mot d'état utilisable par le macroprogramme utilisateur.

Le moniteur TV et le clavier possèdent un autotest intégré permettant à tout moment à l'opérateur de contrôler son poste de dialogue. Pendant le test, le moniteur ou le clavier sont déconnectés de leur coupleur respectif, ce qui permettra des levers de doute pour le deuxième niveau.

6.2 - Maintenance deuxième niveau

Ce niveau correspond à la recherche du sous-ensemble en panne. Outre les tests prévus au premier niveau qui permettent au technicien, à partir d'un guide de localisation, de trouver la panne, le terminal possède de plus, en mémoire morte, des interfaces qui permettent de mettre en place des macroprogrammes de test :

- des liaisons MODEM et CMC par rebouclage,
- de la liaison CALCULATEUR (dans ce cas, c'est le calculateur qui est maître du test),
- de la liaison Bande Magnétique,
- complémentaires de certaines fonctions.

6.3 - Maintenance troisième niveau

C'est la recherche de la fonction en panne à l'intérieur du sous-ensemble avec possibilité d'arriver jusqu'à la plaquette.

Pour cela chaque sous-ensemble a été conçu pour être testé par un banc universel programmé en langage ATLAS.

Le banc a accès au sous-ensemble par des prises de mesure.

Pour le test du microprocesseur, le banc se substitue au panneau technique manuel, ce qui lui permet de tester toutes les micro-instructions de l'unité centrale. Pour le contrôle de son interface Entrée-Sortie, le banc a accès au bus, il peut donc simuler toutes ces configurations.

Pour le test des coupleurs, le mode d'intégration des sous-ensembles (caissons enfichables) permet au banc d'accéder, d'une part au bus, d'autre part aux interfaces d'Entrées-Sorties des coupleurs. Il peut donc, de manière automatique, rechercher un coupleur en panne.

Il faut noter que dans certains cas, pour faciliter les mesures, les fonctions ont été aménagées pour pouvoir être pilotées par le banc (synchronisation externe des fonctions par le banc).

Remerciements :

Le terminal décrit ici a été réalisé sous l'égide de la DTAT/Section d'Etudes et de Fabrications des Télécommunications (DTAT/SEFT).

Nous la remercions ici pour en avoir autorisé la présentation.

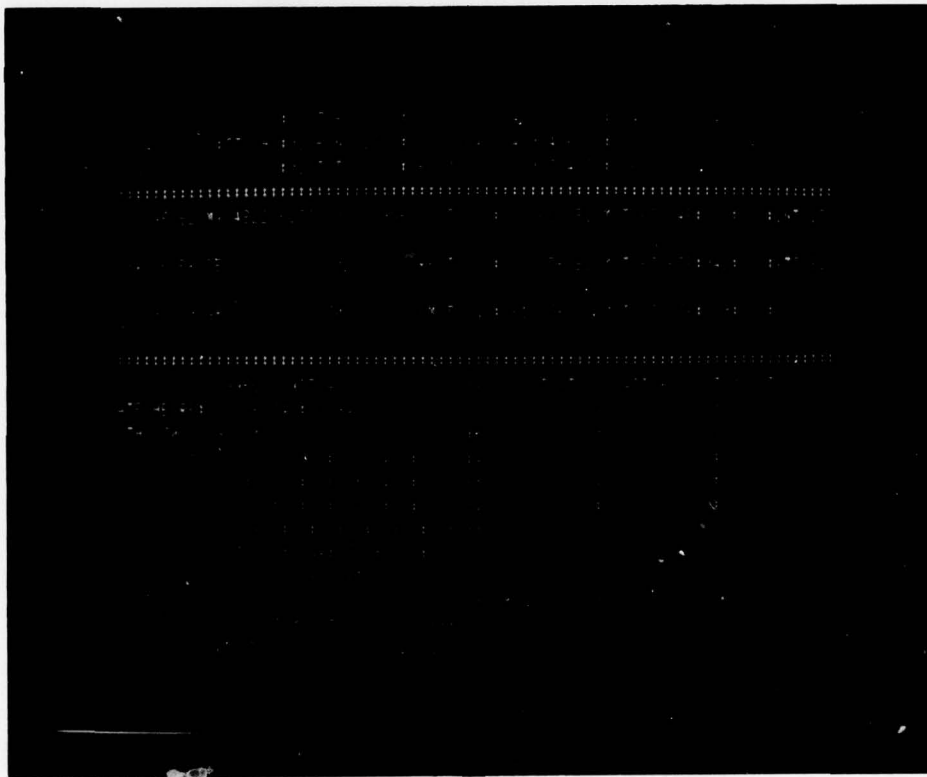
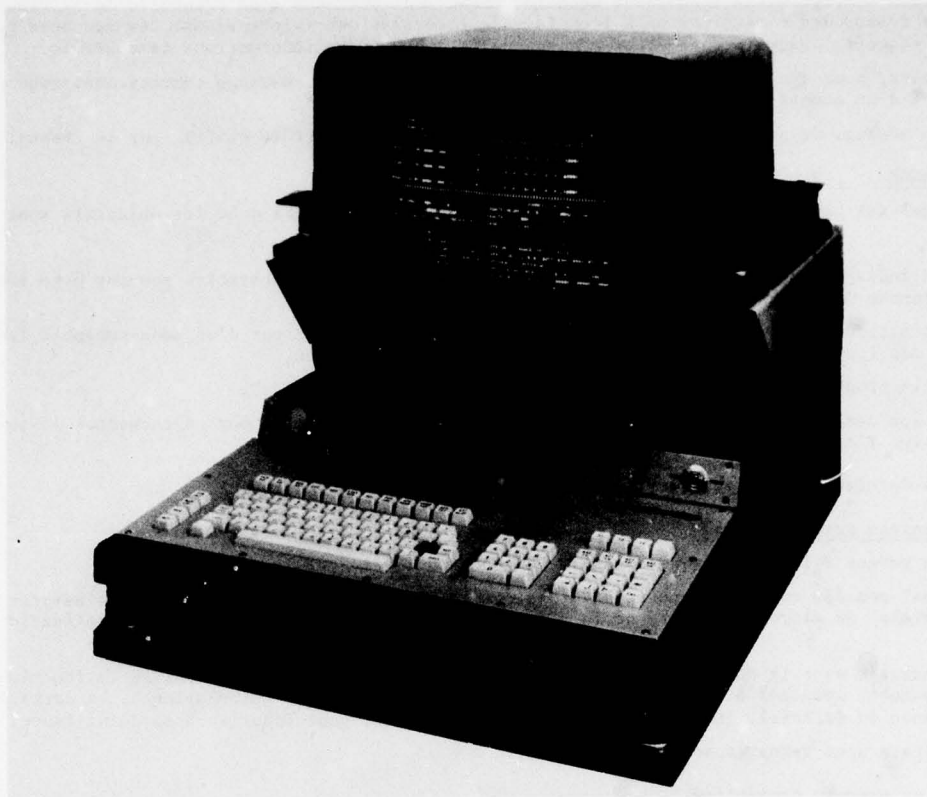


Figure 1

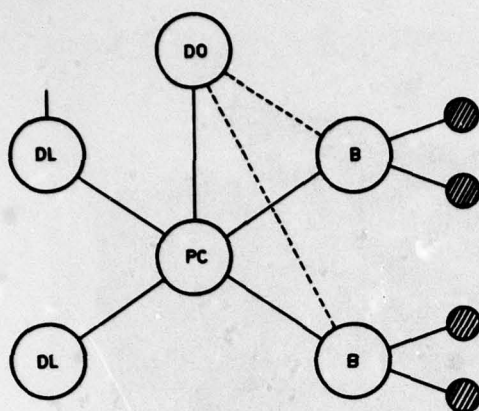


FIG. 2a - RESEAU CENTRALISE, PRINCIPE

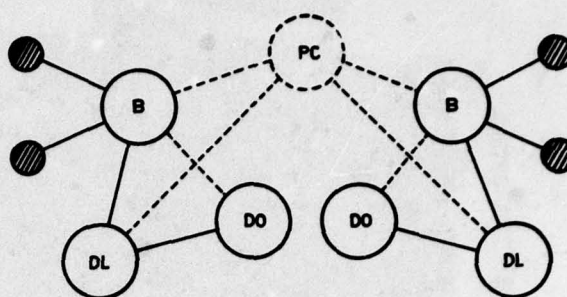


FIG. 2b - RESEAU DECENTRALISE, PRINCIPE

Légendes: ---- Liaisons éventuelles

● Utilisateurs

○ Centre nodal

PC : Poste de Commandement

B : Batterie

DL : Détachement de liaison

DO : Détachement d'observation

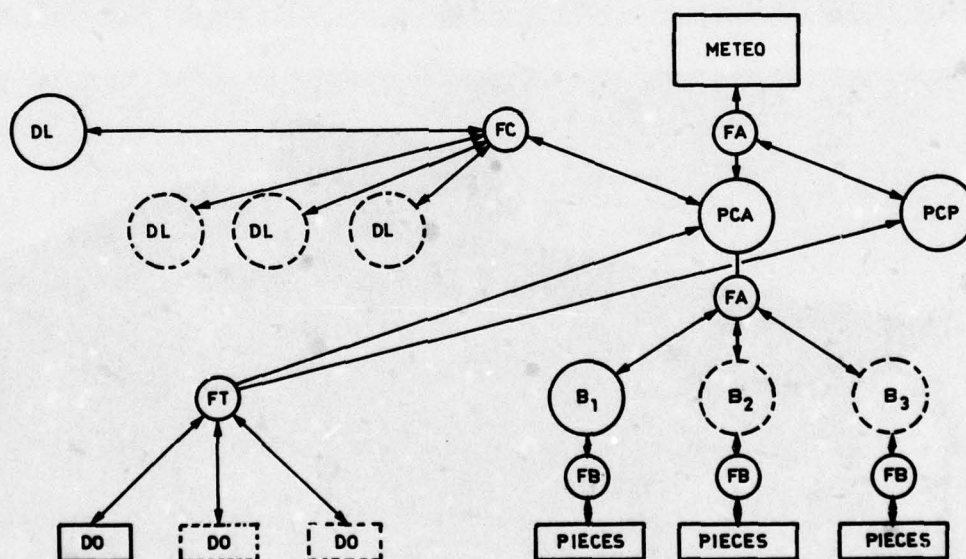


FIG. 2c - ATILA, STRUCTURE CENTRALISEE

Légendes: DO : Détachement observations

DL : Détachement liaisons

B : Batterie

PC : Poste de Commandement

FA FB FC FT Fréquences de communication

○ Centre nodal réalisé par un terminal

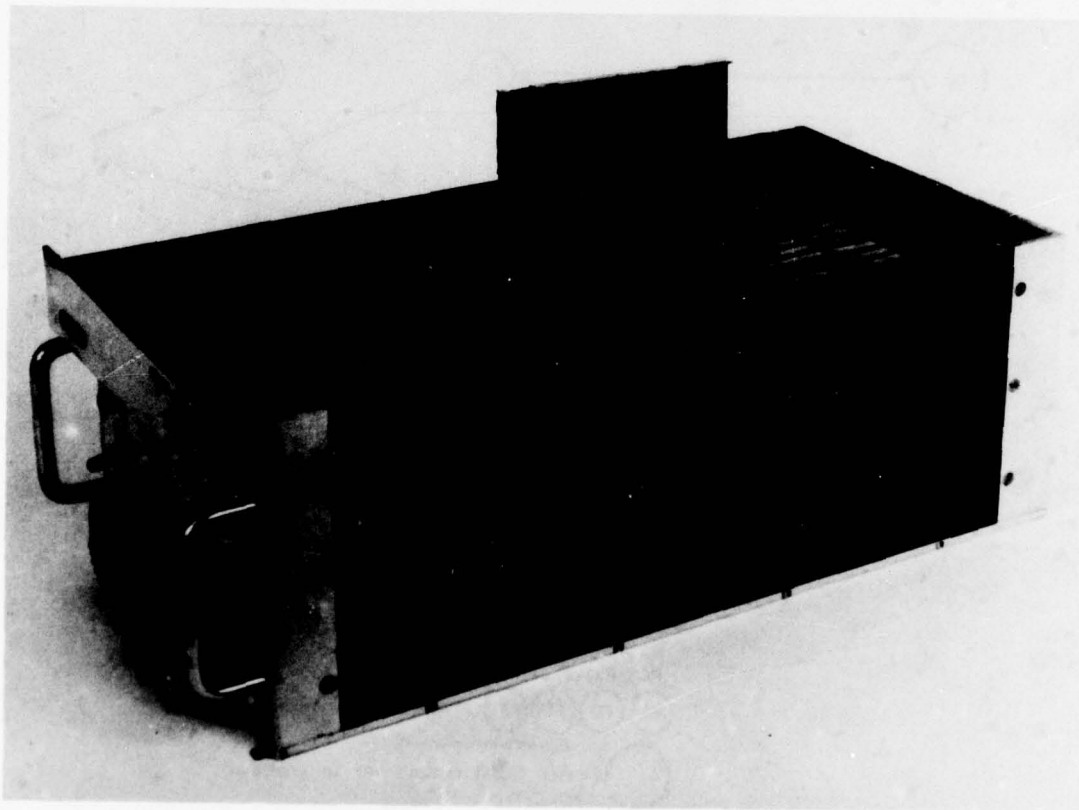
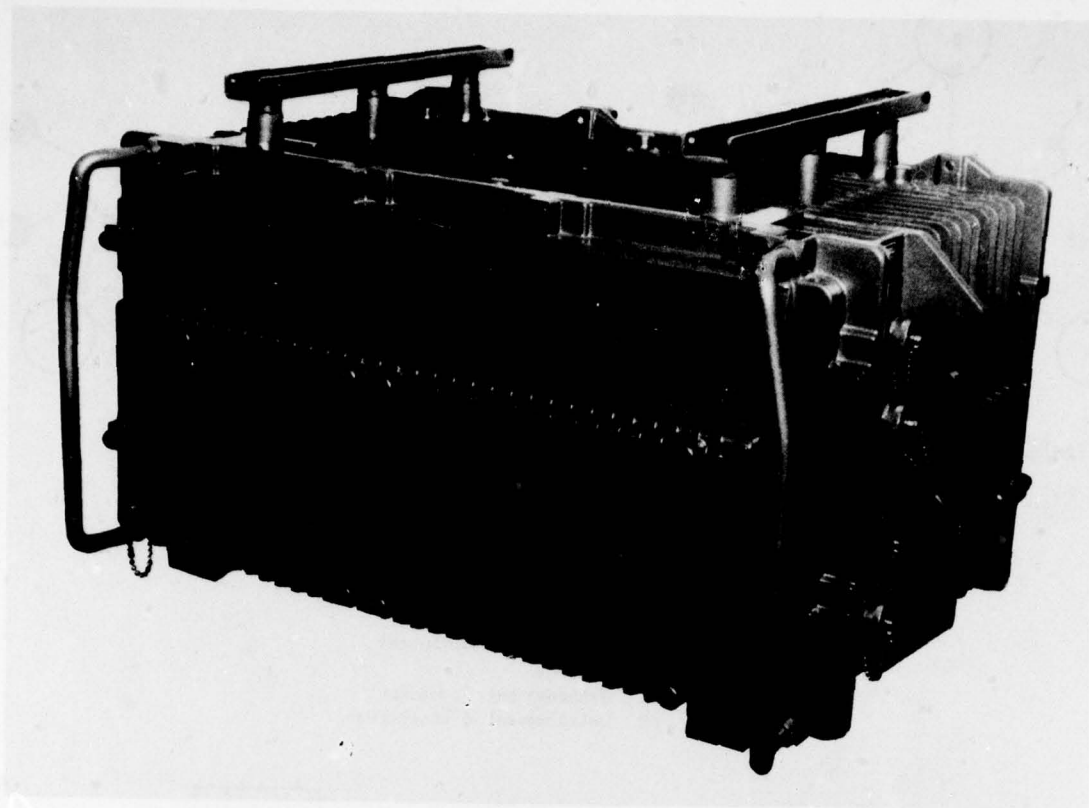


Figure 3

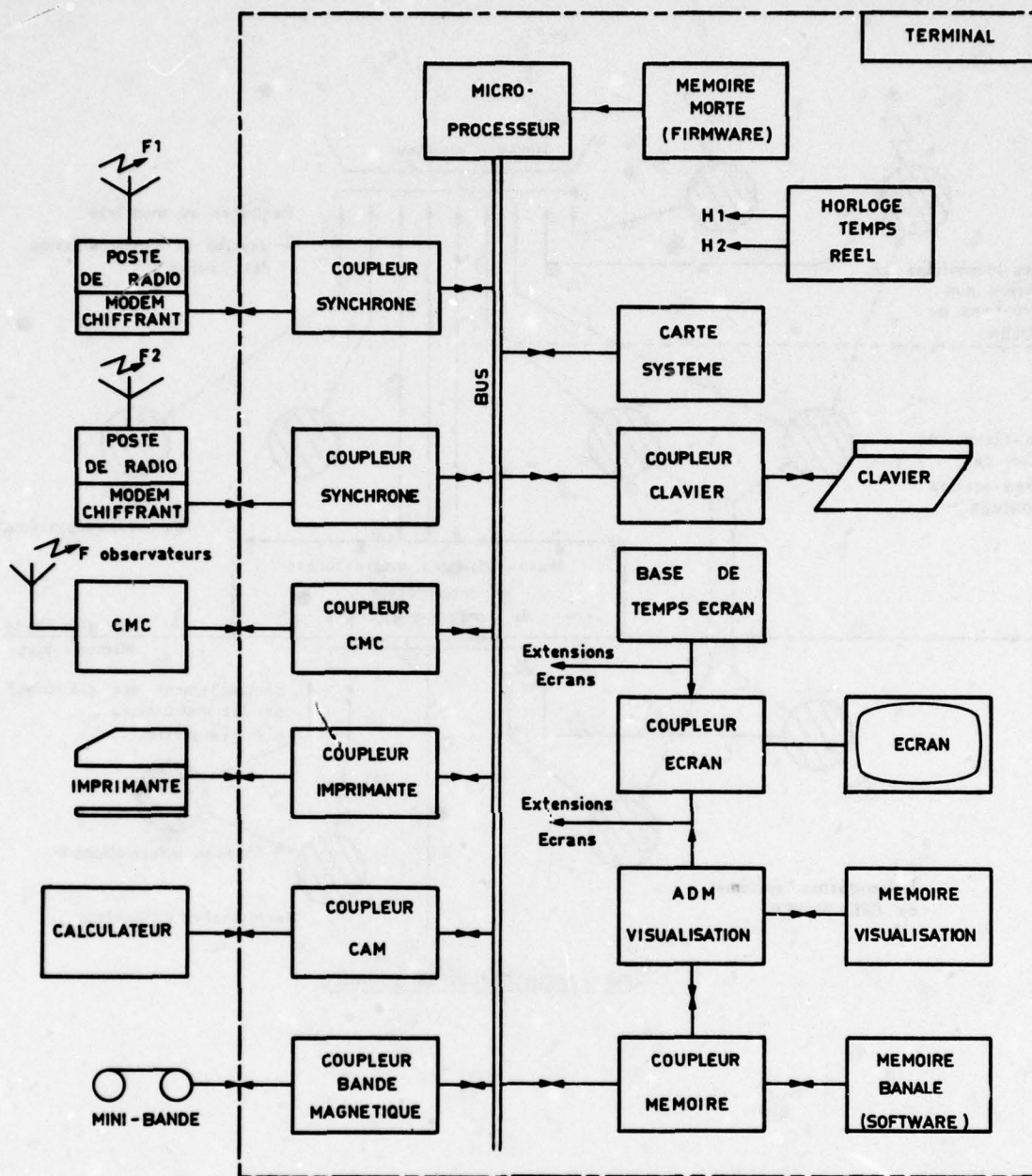


FIG.4 - ORGANISATION FONCTIONNELLE DU TERMINAL

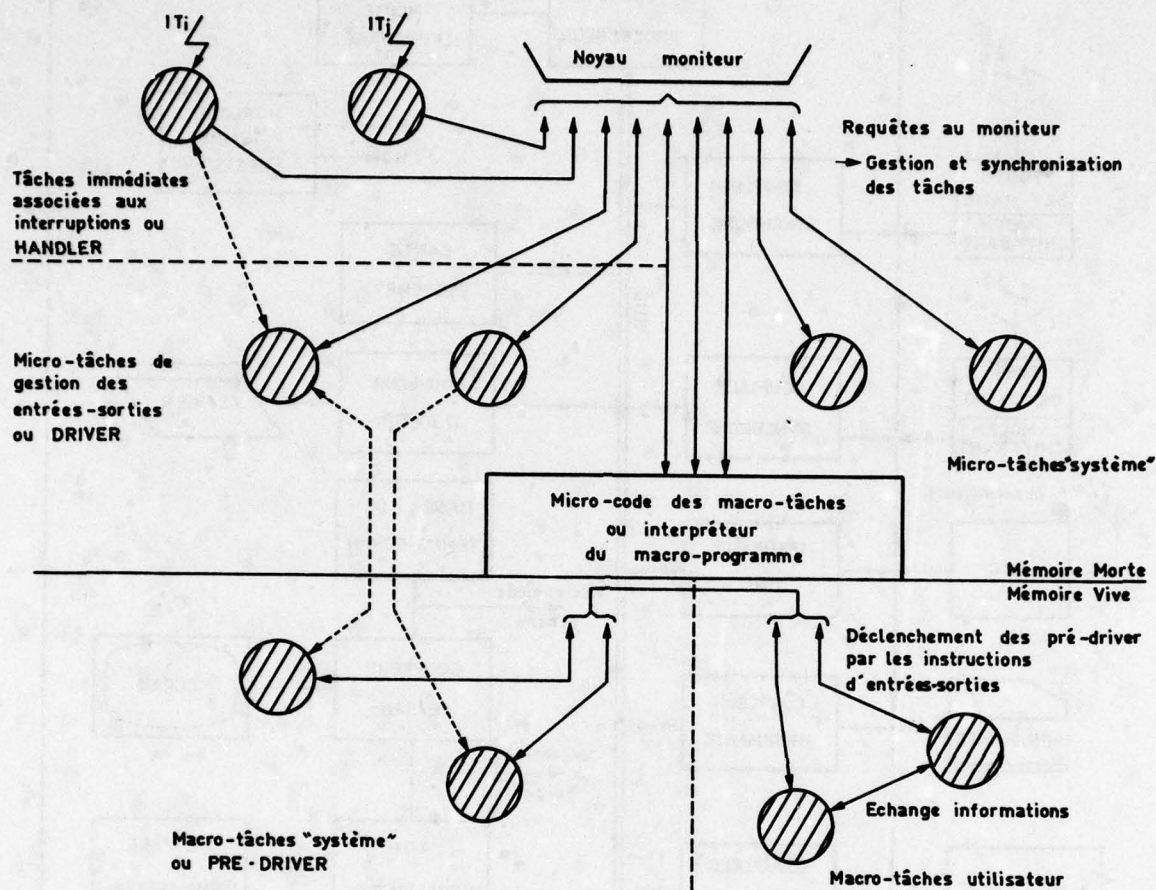


FIG.5: ARCHITECTURE DU LOGICIEL

NOUVELLES GENERATIONS DE MATERIELS TACAN

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RESUME

Une quatrième génération d'équipements de bord fait actuellement son apparition dans laquelle le traitement des signaux vidéo se fait à l'aide de logique programmée, ce que permet l'utilisation des microprocesseurs. De plus, le développement des semi-conducteurs UHF de puissance permet une transistorisation de en plus poussée des équipements.

Les équipements de bord TACAN, dont la tâche est d'extraire du signal reçu des balises au sol les informations de relèvement et de distance, bénéficient particulièrement de ces nouvelles technologies. Le passage de la logique câblée à la logique programmée permet les améliorations suivantes :

- lissage efficace des informations par boucles d'asservissement auto-adaptatives, condition indispensable pour la navigation sur but ;
- calcul de la navigation sur but elle-même.

Le logiciel est partagé en quatre parties, trois parties de traitement proprement dit (azimut, distance, navigation) et une partie moniteur de gestion tenant compte des différents modes de fonctionnement.

Les transistors de puissance UHF permettent la réalisation d'équipements de bord complètement transistorisés dont le principal avantage est la réduction sensible de la puissance dissipée rendant inutile leur refroidissement par air forcé.

LMT réalise actuellement un équipement de bord TACAN utilisant ces nouvelles techniques.

INTRODUCTION

Après trois générations d'équipements de bord où se sont succédées les technologies à tubes, puis à transistors, avec lesquelles les traitements des signaux étaient de type analogique, enfin à circuits intégrés avec des traitements du type numérique, une quatrième génération fait son apparition où la logique programmée vient remplacer la logique câblée de la 3ème génération. C'est avec l'apparition des microprocesseurs et le développement des mémoires mortes (ROM) et des mémoires vives (RAM) à semi-conducteurs qu'est née l'idée qu'on pouvait envisager d'utiliser la logique programmée pour effectuer les traitements relativement simples des signaux TACAN. La souplesse de la logique programmée permettra, comme on le verra, une nette amélioration du lissage des informations TACAN mesurées, condition impérative si l'on veut faire de la navigation de zone avec le TACAN. De plus, la capacité de calcul du microprocesseur est largement suffisante pour faire, en plus, les calculs de changement de coordonnées pour la navigation sur un but déporté par rapport à la balise.

Parallèlement au développement des microprocesseurs, les efforts sont poursuivis pour augmenter les puissances crêtes des transistors UHF, ce qui permet dès maintenant d'éliminer les derniers tubes encore utilisés dans l'émetteur par un amplificateur à transistors. L'avantage qui en résulte est une réduction sensible de la puissance dissipée et la stabilité dans le temps de la puissance HF crête de sortie. Cette baisse de consommation des équipements va permettre leur installation à bord sans refroidissement par air forcé et soulager d'autant la génératrice de bord.

TRAITEMENT VIDEO PAR MICROPROCESSEUR

Rappel du traitement à effectuer

Le signal vidéo à traiter est obtenu après amplification et détection et est régulé en niveau par le CAG dans le récepteur pour être ensuite décodé (fig. 1). Il est constitué, d'une part, d'impulsions gaussiennes de 3,5 μ s de largeur à mi-amplitude, distribuées de façon aléatoire du rythme de 2700 par seconde, d'autre part, des deux types de trains d'une dizaine d'impulsions rapprochées constituant les références du relèvement, les références dites principales à la récurrence 15 Hz, les références dites auxiliaires à la récurrence 135 Hz. L'ensemble des impulsions est modulé en amplitude par 2 signaux sinusoïdaux à 15 Hz et à 135 Hz, chacun au taux d'environ 20% (fig. 2).

Pour obtenir l'information de relèvement, le traitement à effectuer consiste à décoder les 2 types de références, à extraire chaque modulation et à mesurer en terme de phase 15 Hz l'écart entre la référence et le passage positif par zéro de la sinusoïde de modulation.

Pour obtenir l'information de distance, le traitement consiste à extraire des impulsions aléatoires celles qui sont les réponses et qui sont les seules qui soient synchrones des interrogations, puis de déterminer l'écart de temps t mesuré par une horloge à quartz séparant la réponse de l'interrogation correspondante d'où l'on déduit la distance : $\rho = \frac{ct}{2}$ (fig. 3).

Traitement de la distance par logique programmée

En logique câblée, le traitement de la distance consiste à asservir, en la centrant sur l'impulsion réponse, une porte de 10 μ s environ générée par un compteur alimenté par une horloge à quartz et déclenché par l'interrogation. L'asservissement est du second ordre permettant ainsi une mesure de distance sans erreur en défilement. Il est précédé d'une phase d'acquisition où la porte explore successivement les temps de réception des impulsions jusqu'au moment où il rencontre les impulsions réponses synchrones des interrogations pendant quelques cycles consécutifs.

En logique programmée, on utilise le même compteur dont on mémorise, dans une mémoire vive contrôlée par le microprocesseur, les états au moment de la réception des impulsions. Ces états sont des mots de 15 bits et le microprocesseur recherche l'identité des mesures de 2 cycles consécutifs pour extraire les impulsions réponse : c'est la phase d'acquisition. En phase poursuite, la porte de poursuite est générée par un comparateur de bits relié au compteur qui reçoit du microprocesseur l'information de l'instant présumé de réception de la réponse, instant où le compteur de mesure contiendra la valeur de la distance. Le calcul de l'instant est obtenu à partir d'un système d'équations aux différences qui est l'équivalent en logique programmée d'un asservissement du second ordre.

Traitement de l'azimut en logique programmée

En logique câblée comme en logique programmée, l'horloge de mesure d'azimut est générée par un oscillateur asservi sur les trains de références principales et auxiliaires décodés. Un détecteur de crête extrait la modulation composite des impulsions qui, après 2 filtrages, fournit les deux signaux sinusoidaux de mesure 15 Hz et 135 Hz. Une impulsion est créée pour chaque passage positif par zéro de ces signaux.

En logique câblée, on choisit l'impulsion à 135 Hz la plus voisine de celle du 15 Hz qui transfère le contenu du compteur de mesure de relèvement alimenté par l'horloge de mesure et déclenché par l'impulsion 15 Hz de référence. La qualité de la mesure dépend donc essentiellement de la qualité du filtrage des modulations.

En logique programmée, on utilise le même compteur de mesure dont on envoie les contenus (mots de 12 bits) au microprocesseur au moment de l'arrivée des impulsions issues des sinusoides 15 Hz et 135 Hz de modulation. Le traitement va consister à déterminer l'impulsion 135 Hz la plus voisine de celle du 15 Hz et à effectuer des calculs sur les relèvements mesurés à partir d'un système d'équations aux différences (comme pour la distance) pour obtenir, là aussi, un asservissement du second ordre qui va parfaire le filtrage des modulations.

AVANTAGES ET POSSIBILITES SUPPLEMENTAIRES OFFERTS PAR LA LOGIQUE PROGRAMMEE

Boucles d'asservissement auto-adaptatives

Dans le traitement de la distance comme dans celui du relèvement, on a vu qu'on effectuait des calculs à partir d'un système d'équations aux différences. On calcule, à chaque échantillon, la différence entre valeur estimée et valeur mesurée en utilisant le système d'équations suivant :

$$\text{Erreur}_n = \text{Valeur mesurée}_n - \text{Valeur estimée}_n$$

$$\text{Vitesse}_{n+1} = \text{Vitesse}_n + (K_2 \times \text{Erreur}_n)$$

$$\text{Valeur estimée}_{n+1} = \text{Valeur estimée}_n + K_1 \times (\text{Erreur}_n + \text{Vitesse}_{n+1})$$

La valeur mesurée à l'échantillon n permet de calculer la vitesse estimée à l'échantillon $n+1$, et la valeur estimée à l'échantillon $n+1$. On montre facilement que ce système de 3 équations définit une relation entre les valeurs estimées et les valeurs mesurées aux instants $n+1$ et $n-1$ caractéristique d'un système du second ordre.

En logique câblée, on a vu que pour la distance le même traitement est effectué, mais les coefficients K_1 et K_2 sont déterminés une fois pour toutes. Or ces valeurs sont un compromis pour obtenir un lissage acceptable n'entraînant pas d'élargissements trop importants de l'erreur au cours de la stabilisation de l'asservissement (fig. 4). La mesure reste ainsi encore sensible au bruit qui est important surtout au seuil de sensibilité du récepteur et particulièrement en relèvement. Il serait donc souhaitable d'utiliser deux ou trois jeux de coefficients, l'asservissement commençant avec le jeu offrant la moins bonne stabilité, mais la moindre élargissement pour terminer avec les coefficients permettant le lissage le plus efficace (fig. 5).

Il est possible d'utiliser ces boucles auto-adaptatives en logique câblée, mais c'est au prix d'une trop grande complication des circuits. En outre, toute modification des valeurs des coefficients, entraîne une modification importante des circuits.

En logique programmée, au contraire, doubler ou tripler le jeu de coefficients n'entraîne qu'un accroissement du nombre d'instructions du programme. Il faut remarquer également la souplesse du système puisque modifier la valeur des coefficients n'entraîne que la reprogrammation d'une mémoire morte.

En outre, la précision de l'asservissement découlant en particulier des mesures sur les vitesses peut être très grande en logique programmée. En effet, en logique câblée, le pas du compteur de vitesse est limité pour ne pas compliquer les circuits (en distance, par exemple, les incréments sont de l'ordre de 50 noeuds) alors qu'en logique programmée, la résolution en vitesse est adaptée au défilement et peut être ainsi très grande aux faibles vitesses (pour reprendre le même exemple de la distance, on peut obtenir facilement une résolution de l'ordre du noeud). Il en résulte l'avantage qu'en cas de perte de l'information, le système peut passer en mémoire dynamique avec de faibles dérives.

Le lissage des informations relèvement et distance TACAN ainsi obtenu est indispensable si l'on veut faire les calculs permettant la navigation sur un but déporté par rapport à la balise (ou la navigation de zone). On montre facilement, en effet, qu'avec certaines configurations géométriques, les fluctuations des informations TACAN, mêmes faibles, entraînent des fluctuations très importantes des coordonnées calculées.

Possibilité de calcul de navigation

Lorsqu'il y a présence dans le même équipement de navigation d'un moyen de calcul et des coordonnées polaires par rapport à une balise au sol, il est naturel d'effectuer les calculs de changement de coordonnées sur un but dont on aura entré les coordonnées par rapport à la même balise (fig. 6).

ρ_T et θ_T sont les coordonnées de la balise TACAN par rapport à l'avion.

ρ_0 et θ_0 sont les coordonnées du but par rapport à la balise TACAN.

ρ_B et θ_B sont les coordonnées du but par rapport à l'avion.

Les équations à résoudre sont évidentes :

$$\rho_B \cos \theta_B = \rho_T \cos \theta_T + \rho_0 \cos \theta_0$$

$$\rho_B \sin \theta_B = \rho_T \sin \theta_T + \rho_0 \sin \theta_0$$

On en déduit :

$$\rho_B = \sqrt{\rho_B^2 \cos^2 \theta_B + \rho_B^2 \sin^2 \theta_B}$$

$$\theta_B = \text{Arc tg } \frac{\rho_B \sin \theta_B}{\rho_B \cos \theta_B}$$

Les algorithmes effectuant ces calculs sont bien connus.

On peut calculer les quantités $\sin \theta$ et $\cos \theta$ par programme ou plus simplement les obtenir à l'aide d'une mémoire sinus, ce qui permet de réduire sensiblement le temps de calcul.

Si l'on entre également l'angle d'une route θ_r à suivre passant par le but (fig. 6), les opérations suivantes sont aussi aisément effectuées :

- calcul de la déviation de la route à suivre : $\theta_B - \theta_r$
- calcul de l'écart latéral à la route l
- calcul de la distance orthogonale au but d.

Un exemple de réalisation à LMT

Pour juger les avantages du traitement vidéo par logique programmée des informations TACAN, le STTA nous a aidé à réaliser et à tester en vol, avec l'aide du CEV, un prototype de vidéo TACAN à microprocesseur. Cette vidéo est installée sur deux cartes imprimées en lieu et place des circuits vidéo à logique câblée d'un équipement TACAN de bord.

Le logiciel est divisé en 4 parties :

- une partie relèvement,
- une partie distance,
- une partie affichage et contrôle des coordonnées du but déporté et calcul de navigation,
- une partie moniteur de gestion.

Le moniteur classe et répartit dans le temps les différents traitements à effectuer en tenant compte des différents modes de fonctionnement du TACAN de bord : réception seule (sans distance), normal, air-air (distance seulement), et des différents modes d'utilisation du système (coordonnées TACAN ou coordonnées du but déporté).

Le microprocesseur du type N MOS est un 8 bits. Il est couplé à une mémoire vive (RAM) de 256 octets.

Le programme relèvement contient 650 instructions et s'exécute en 3,5 ms.

Le programme distance contient 560 instructions et s'exécute en 1,5 ms.

Le programme calcul de navigation contient 700 instructions et s'exécute en 80 ms. Il faut signaler que le traitement est totalement effectué par programme et que ce traitement serait réduit à quelques ms si l'on utilisait des mémoires sinus.

L'ensemble des programmes, y compris le moniteur, contient 2500 instructions représentant 4800 octets répartis sur 5 mémoires mortes programmables (PROM) de 1024 octets chacune.

Du fait des dimensions importantes des composants, tels que le microprocesseur, les mémoires vives et mortes, les mémoires tampon d'entrées-sorties, les dimensions des circuits sont à peu près les mêmes en logique programmée qu'en logique câblée (fig. 7 et 8).

La consommation sur les tensions d'alimentation est un peu plus importante qu'avec la logique câblée (qui utilise la logique TTL LS) bien que le microprocesseur soit en technologie N MOS, mais les organes d'entrées-sorties et les mémoires mortes programmables actuellement disponibles sur le marché consomment beaucoup. On peut espérer que des progrès seront faits prochainement dans ces domaines.

L'importance de la mise au point de la programmation est évidente dans la mesure où l'on cherchera à réduire au maximum la longueur du programme, ce qui permettra de gagner à la fois du temps et des mémoires et donc de minimiser le nombre de circuits et la consommation. D'où l'emploi du langage assembleur ou, sinon, d'un langage ayant réellement un très faible taux d'expansion.

Les informations numériques de distance et de relèvement sont directement calculées dans le format utilisable par les indicateurs TACAN à entrées numériques. L'affichage des coordonnées du but se fait par commutation d'un mode spécial où l'une, puis l'autre des sorties numériques est incrémentée à accélération constante dans les deux sens. Comme les sorties numériques sont visualisées par l'indicateur, on arrête l'incrémentation lorsque l'indicateur affiche la valeur désirée qui est alors stockée dans une mémoire vive de la vidéo.

Pour illustrer l'efficacité du lissage apporté par la logique programmée par rapport à la logique câblée, on a enregistré, pour les 2 logiques, sur une table traçante, les fluctuations de l'information de relèvement pour deux types de signaux : signal confortable de -70 dBm (fig. 9) et signal faible de limite de portée de -90 dBm (fig. 10) générés par un simulateur de balise TACAN. Les figures 9 et 10 montrent l'amélioration considérable apportée par la logique programmée, puisque dans les deux cas la fluctuation est réduite aux fluctuations du bit le moins significatif (LSB) du mot numérique de sortie (environ 0,1°).

ÉMETTEUR 1 KW A TRANSISTORS

Quelques fabricants de semi-conducteurs se sont lancés à la course aux puissances crête dans la bande L et échantillonnent depuis quelque temps les transistors capables de fournir 400 W crête dans la bande TACAN. À l'aide d'anneaux hybrides, on peut coupler 4 transistors, ce qui permet de réaliser un émetteur sortant 1 KW crête dans la bande TACAN.

Du fait des importants courants crête qui en résultent (70 A crête), des précautions spéciales doivent être prises pour obtenir la modulation gaussienne et un spectre correct.

LMT a réalisé une chaîne d'émission complète comprenant 10 transistors excités par le synthétiseur (sortie 200 mW) (fig. 11).

Les avantages d'un tel émetteur sont évidents :

- considérable réduction de la puissance dissipée alors qu'en recherche distance (300 impulsions émises) un émetteur à 4 tubes consomme plus de 40 W du fait du chauffage régulier des tubes et des pertes du générateur THT, un émetteur à transistors ne consomme que 5 W. De plus, alors qu'à faibles taux d'émission (cas le plus fréquent : poursuite distance, 50 impulsions émises) l'émetteur à tubes consommera une puissance à peine réduite, la consommation de l'émetteur à transistors est proportionnelle au taux d'émission,
- absence de THT (50 V suffisent) et des contraintes qui en résultent (fiabilité, tenue en dépression, etc...),
- stabilité dans le temps de la puissance émise alors que les tubes vieillissent (époussetage de la cathode),
- possibilité de fonctionnement dégradé puisque du fait de l'anneau hybride une défectuosité de l'un des 4 transistors de sortie de l'émetteur ne réduira la puissance crête de sortie que de 2 dB et assurera encore un service appréciable.

DESCRIPTION D'UN TACAN DE BORD UTILISANT CES TECHNOLOGIES AVANCÉES

LMT développe un TACAN de bord qui intègre ces nouvelles possibilités.

Du fait de l'émetteur et de l'utilisation de logique à faible consommation (TTL LS), la consommation de ce TACAN de bord est inférieure à 80 W, ce qui est une baisse sensible par rapport à la génération précédente (170 W) et rend inutile le refroidissement par air forcé.

CONCLUSION

La miniaturisation du matériel d'informatique comme les mémoires et les microprocesseurs vient battre en brèche certaines idées qui avaient cours il y a quelques années, où l'on imaginait un calculateur de bord central et puissant exploitant les données brutes des différents senseurs devenus incapables du moindre traitement. Avec la logique programmée, l'informatique se démystifie peu à peu, les senseurs qu'on voulait rendre bornés deviennent intelligents, tandis que le calculateur de bord va exploiter mieux et avec plus d'efficacité leurs données élaborées, tant il est vrai qu'il est plus enrichissant de converser avec des êtres intelligents qu'avec des êtres bornés.

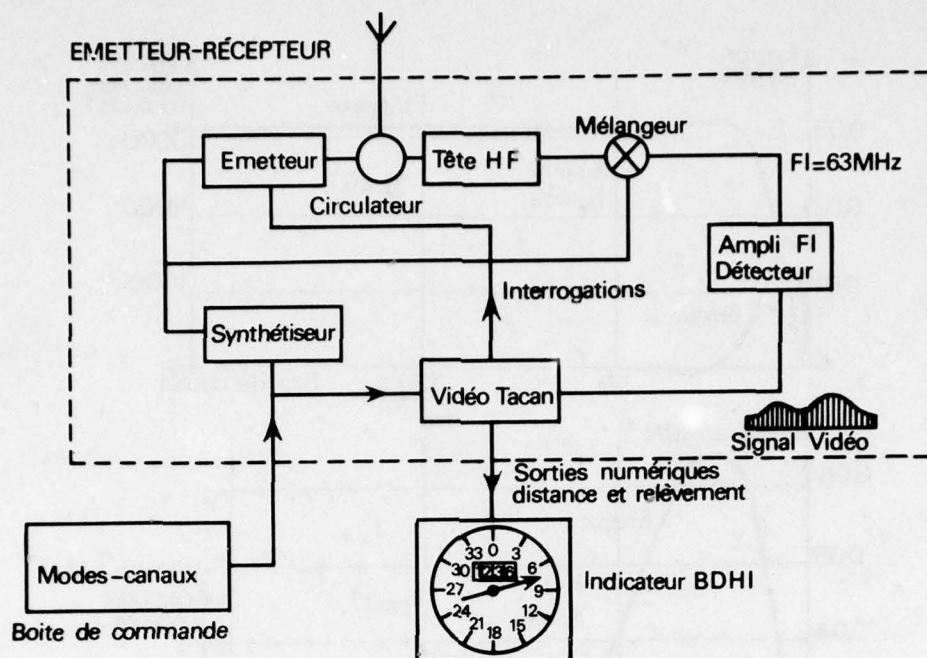


FIG. 1 - Schéma synoptique d'un équipement de bord TACAN.

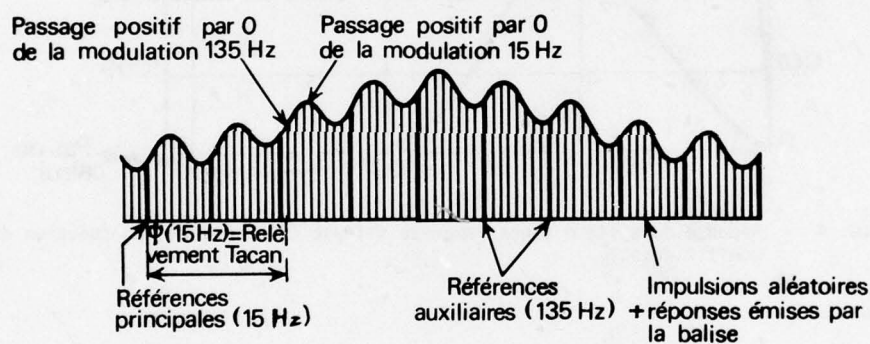


FIG. 2 - Signal TACAN.

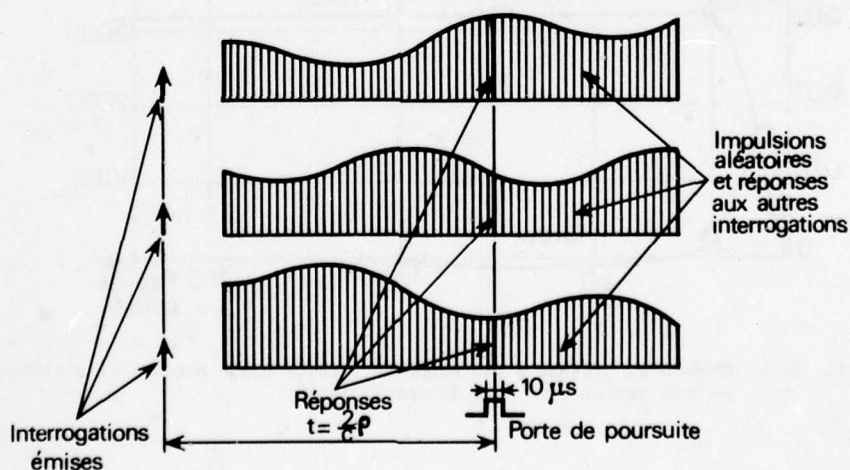


FIG. 3 - Synchronisme des impulsions de réponse.

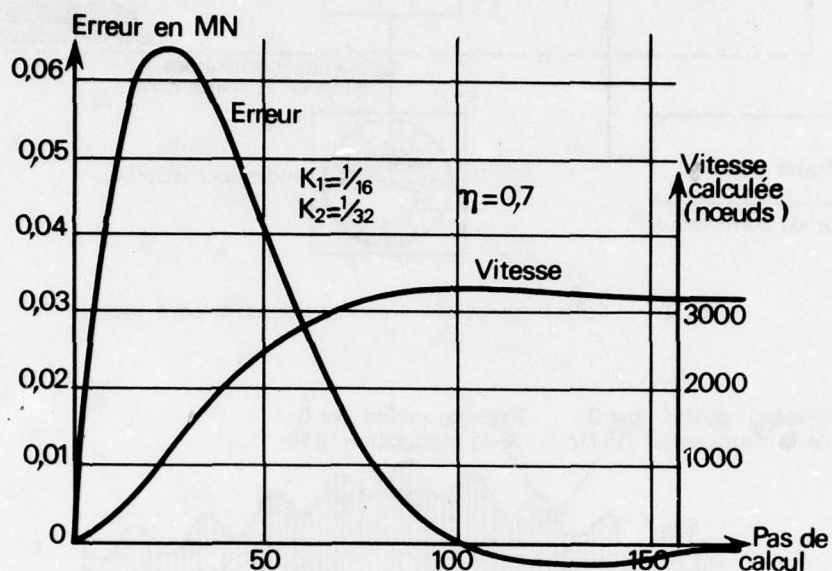
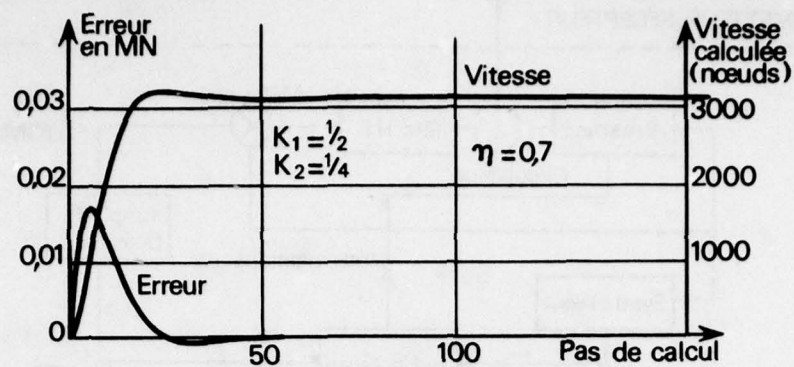


FIG. 4 - Réponse du système à une rampe de vitesse (3150 noeuds) en fonction des coefficients.

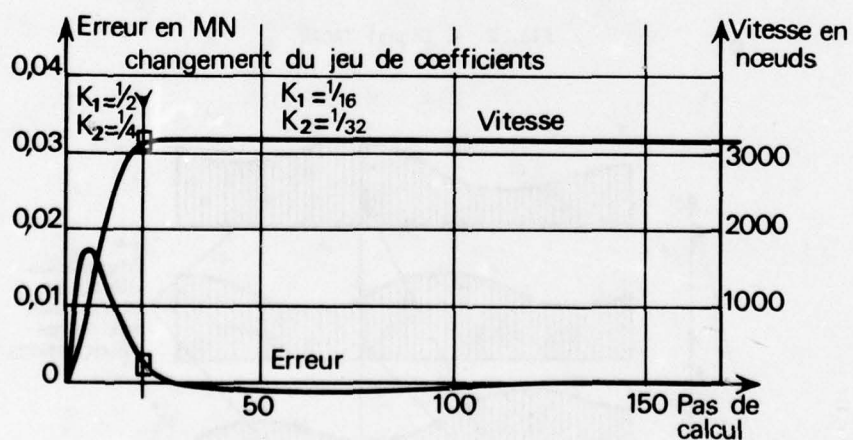


FIG. 5 - Réponse du système à une rampe de vitesse (3150 noeuds) en utilisant successivement deux jeux de coefficients.

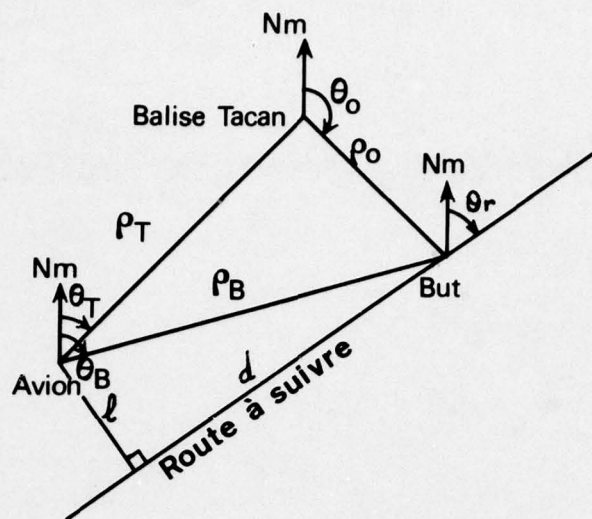


FIG. 6 - Navigation sur un but déporté par rapport à la balise TACAN.

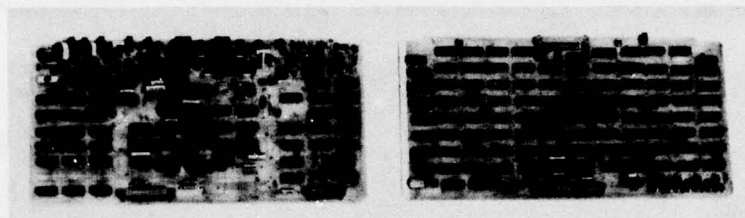


FIG. 7 - Vidéo à logique câblée.

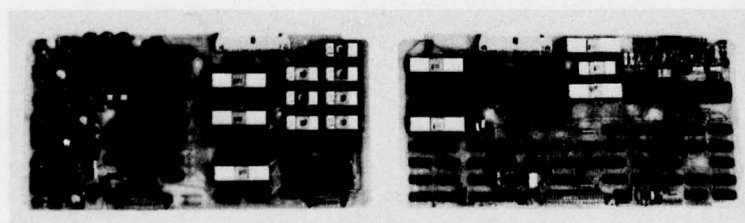


FIG. 8 - Vidéo à logique programmée.

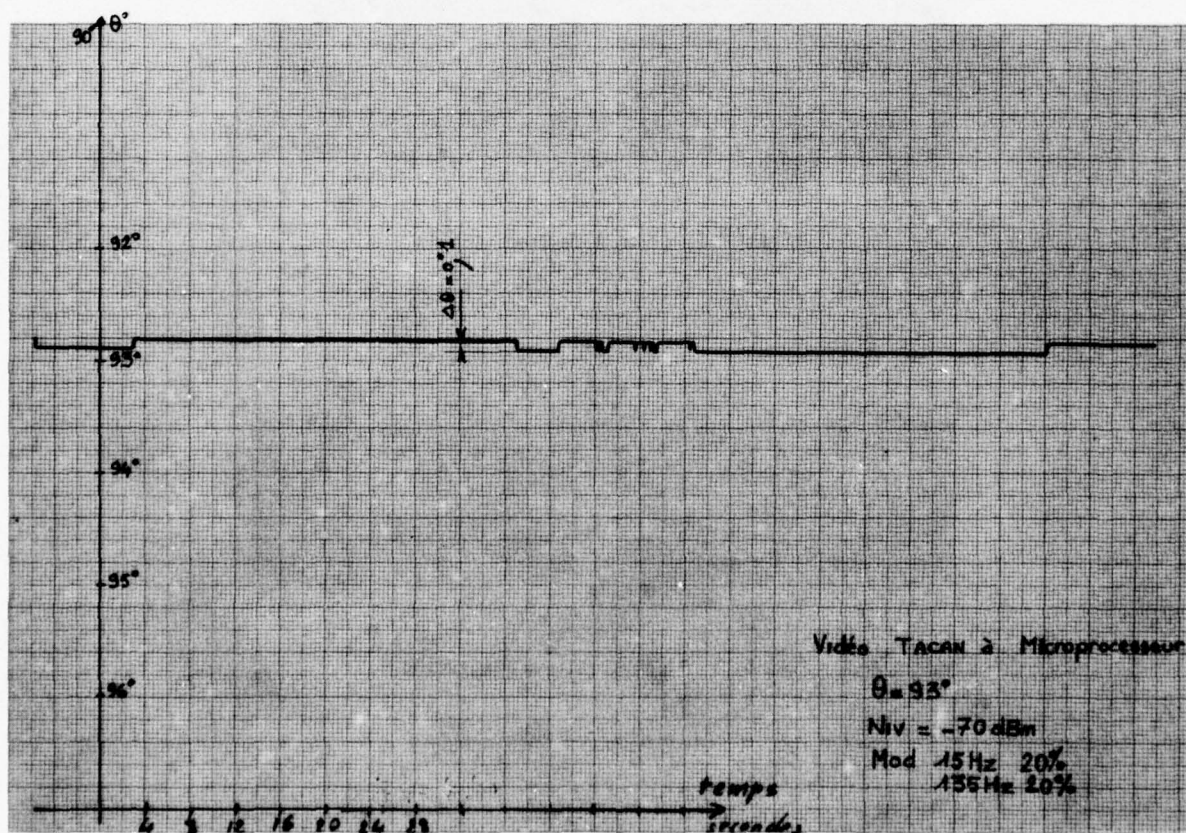
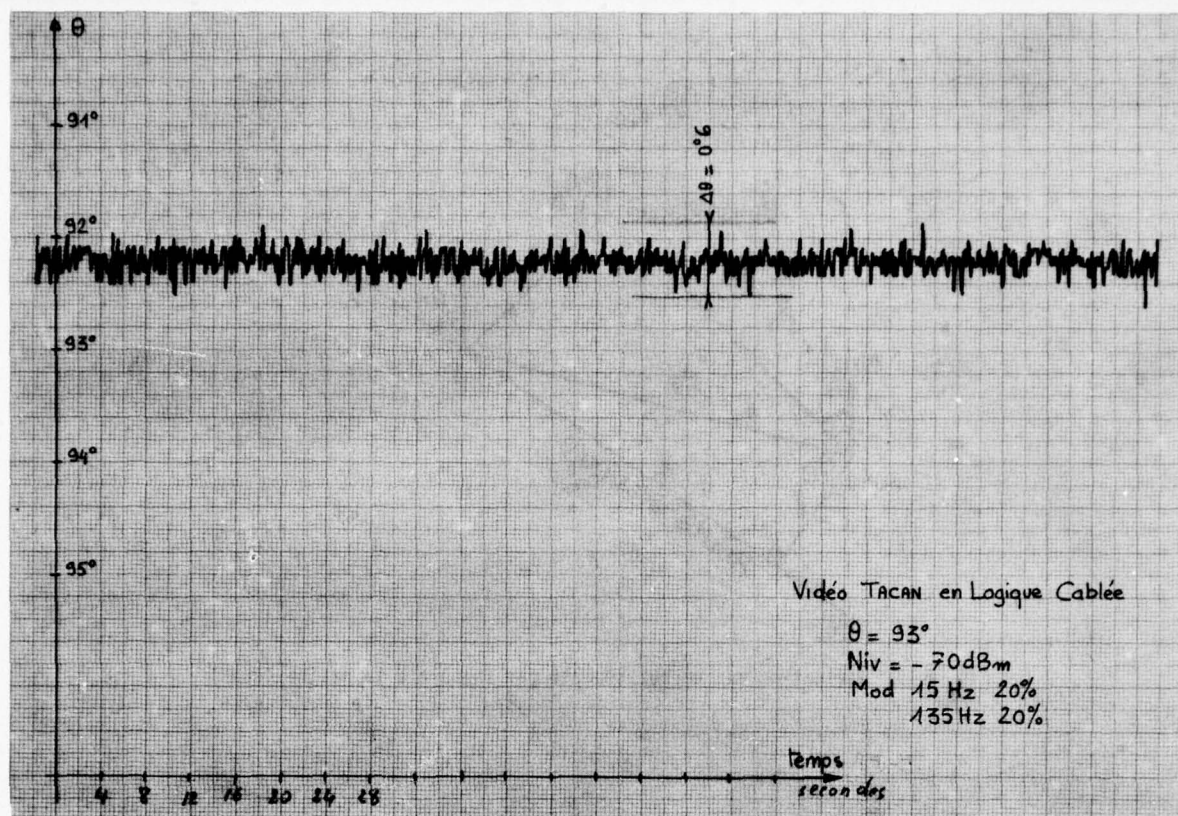


FIG. 9 - Fluctuations comparées de l'information de relèvement entre vidéo à logique câblée et vidéo à logique programmée pour un signal confortable (-70 dBm).

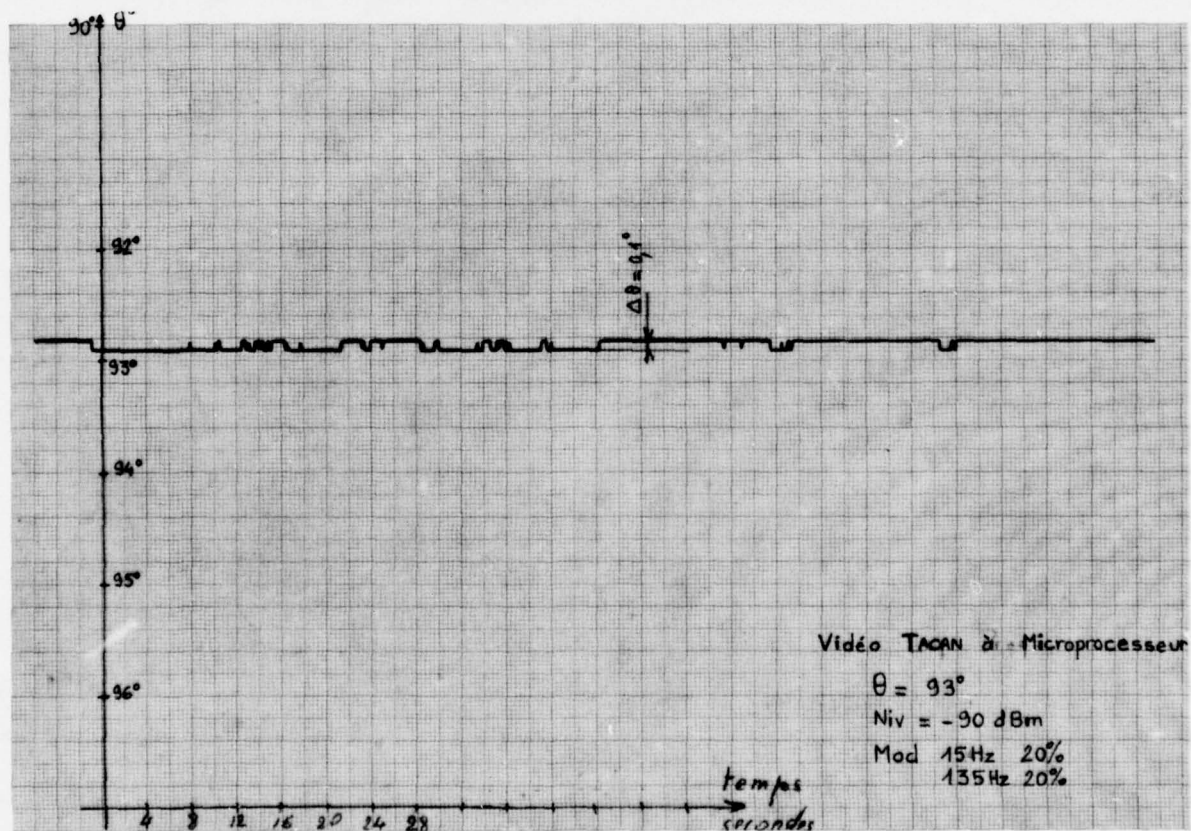
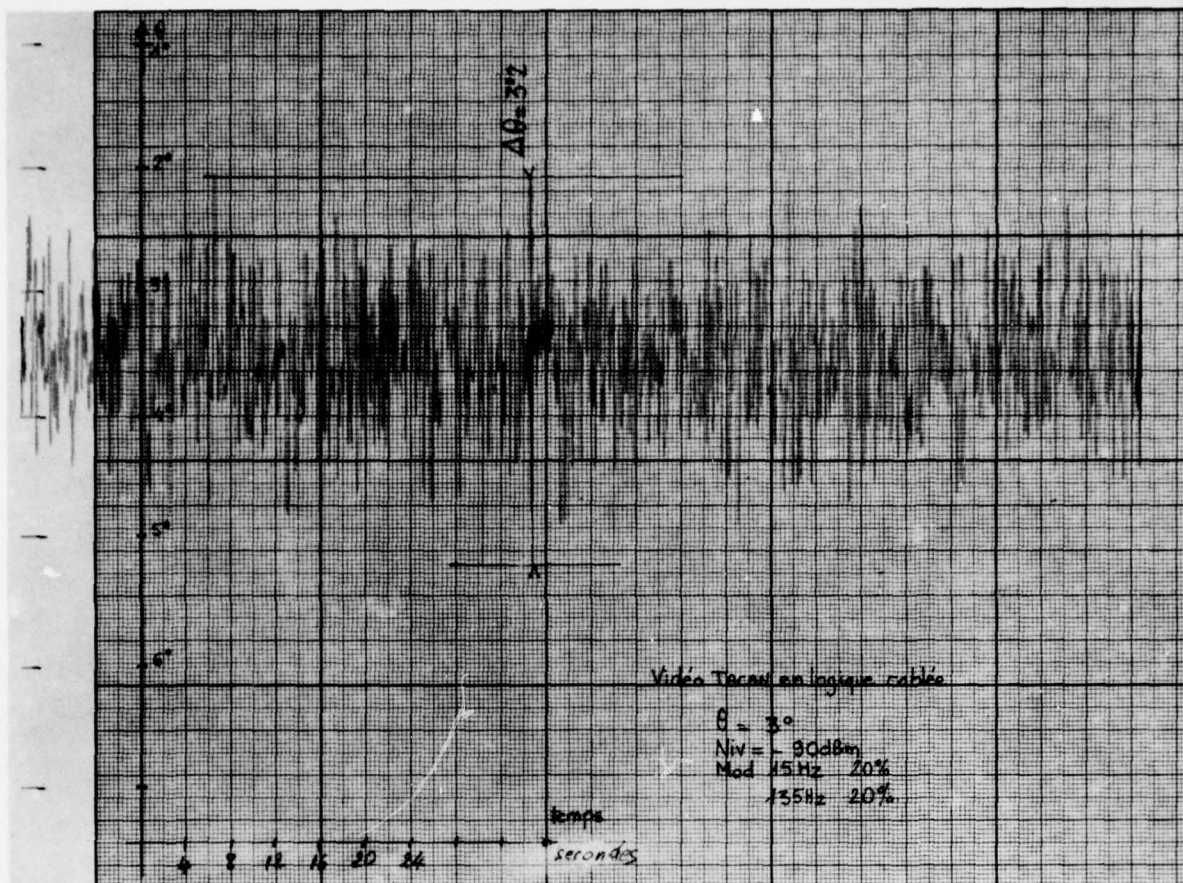


FIG 10 - Fluctuations comparées de l'information relèvement entre vidéo à logique câblée et vidéo à logique programmée pour un signal faible (-90 dBm).

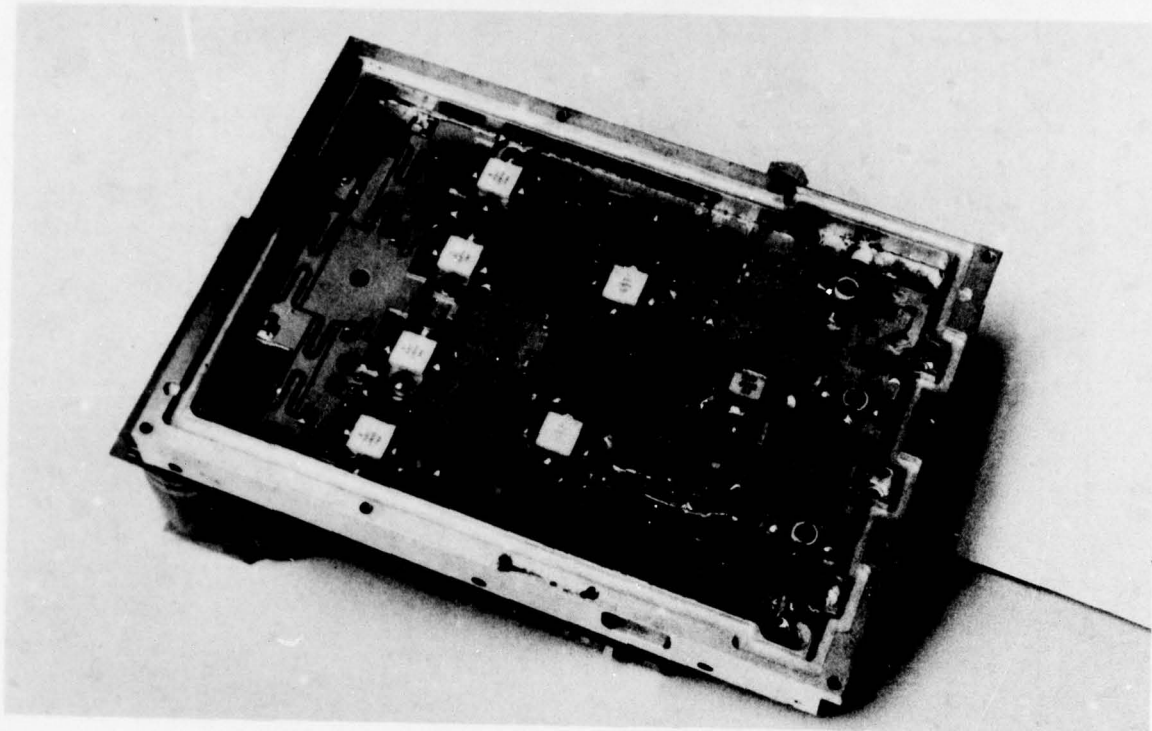


FIG 11 - Emetteur 1 KW transistorisé pour TACAN de bord.

DATA PROCESSING OPPORTUNITIES 1980-1990

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SUMMARY

This paper discusses two important operational problems, the automation of Command and Control (C²) and the associated data processing interoperability problems. The C² automation is beset with the problems of flexibility and adaptability and requires a methodology that allows evolutionary improvement to the computer hardware and software systems. Two primary technologies which could assist in the automation of C² are Software Engineering and Knowledge-based Systems. The Software Engineering technology could make the software system function more visible, both to the programmers and the staff officers, for easier modification as requirements change. Cognitive aids and Knowledge-based Systems can bring the computer to bear on reducing the complexities of the C² situation so that the human can more readily grasp the alternatives and pay-offs in a battle situation. The increased degree of automation in C² will demand a high degree of interoperability among these C² computer systems. Essentially what is required is the ability for computers to communicate with other computers without human intervention unless the situation changes such that the information exchanged and the information paths must be changed quickly in a battle situation, in which case flexibility in the information network is required. The technology of Distributed Data Processing attempts to address this latter problem.

INTRODUCTION

This paper's title might suggest that it will be the typical "Gee-Whiz, look what we computer people are going to have available to dazzle you with in the next 20 years." It could be an exhaustive expose of the higher speed, smaller size, cheaper hardware gadgetry expected, and the clever things you will be able to do with the future software and system architectures. I will get into some of this but only as it applies to what I consider highly important tactical military problems. Instead, I will be more problem-oriented by attempting to define operational problems in the Information Processing area, and to identify technological advances that might be applied to these.

My perspective indicates that two of the more important operational problems associated with Information Processing are:

1. The automation of Command and Control in light of the tremendous increase in the volume of data, the complexity of the decision alternatives, and the more timely responses required; and
2. The distributed data processing situation in light of the increased automation and the need for survivability in the tactical environment.

I will take each problem in order, discussing and defining it, and then offering some potential technology opportunities that might be applicable.

COMMAND & CONTROL CENTER AUTOMATION

Traditionally the data processing community has predicted glorious and wonderful advantages in using the latest gadgetry in the computer world. For some time this was the thing to do until the business and military world woke up to the fact that some of those glorious and wonderful things were not occurring. However, it must be admitted that the business world has tremendously exploited the use of computers for such applications as science, accounting and business. If one looks into this one quickly realizes that the reason for success in these areas is that their functions are not only fairly routine but they are well defined to the point of being described mathematically. In other cases, such as airline reservations, the human oriented process could be described explicitly and an algorithm, however complex, generated. These are the type of applications that have taken advantage of the computer.

Once one gets past the routine and the well defined and gets into the higher order of management which involves more cognitive functions, one finds the computer little used. There have been many attempts to extend Management Information Systems into supporting these processes in the management area but most have fallen short of expectations. Management Information Systems have been built that do a fine job of collecting much data and producing reports; however, they have not made it easy for several levels of management to operate on this data base with the latest operations research techniques or with their own decision making processes that have been developed over the years by the individual. It still requires a staff of specialists in operations research to apply various decision modeling techniques. The average marketer, salesman, warehouse manager or purchasing agent does not or cannot use these aids. These aids by their nature require the use of a computer and we have not addressed well the problems associated with the man-machine interaction requirements for using these aids.

The military has copied the business community in exploiting computers for business and administration, and have led the business community in the application of computers to scientific and technical areas, such as surveillance, weaponry, vehicle guidance, etc. Again, the military has applied the computer on well defined problems. There are instances in C&C and Intelligence Analysis in which procedures have been automated very cleverly, still it is a prerequisite that the computer has been applied well only where we have defined the problem well.

In those instances we seem to have removed the flexibility we used to have with the manual or semi-automatic systems. The humans in the system have lost the ability to step in and interject changes in the process or to view situations in a different way. I conclude that we have not provided a window into the automated process that would give the user the visibility and insight he needs to do things differently than planned. You only have to look at such systems as airline reservations, banking, accounting, and most inventory control to realize how little control the user has over these systems once the programmer has gone home.

There is one area in the military environment that as yet defies satisfactory automation, and that is the decision making process associated with Command & Control (C&C). The problem here is fundamental in that no one understands the decision process well enough to document it in a meaningful way. We have made attempts at automating this process by starting with the definition of the data available and the routine functions performed on such data. We have made considerable progress in establishing computerized data bases within a single C&C Center and displaying summaries of such data, but even here we are frustrated in our attempts to completely specify the sources of the data and the recipients of the data.

The next usual approach in C&C automation has been to attempt to define those functions which we feel are fairly stable. I suspect that most of these functions are either heavily oriented toward peace time operation of the C&C system or are those functions that by tradition have been fairly well defined in war time. I think we are all aware that there is an uneasiness that we may not have done this well for the battle situation and are desperately looking for some way of exercising these systems to see if they can handle the situation. At a conference last year in Boston on C&C decision making, a number of high level military strategists who have participated in C&C exercises indicated that they had little confidence in the computer system and would rather take a small group of extremely capable staff officers and go off in the corner with a batch of telephones.

Again, I think that we have not built into the automated C&C process that necessary window which would provide us the visibility needed for adaptability in real situations. I think it is well recognized that we haven't been able to, and we probably should not try to, define the high order cognitive functions at the various staff and command levels. Both business management and military tactical management are sufficiently complex and unpredictable that the automated systems must adapt to these cognitive thinkers.

What can be done about this? I would suggest the following:

1. We continue to automate the routine, definable functions in order to cope with the amount of data and to reduce manpower. This is done through the software design, development and testing process, but we need to universally apply the latest software engineering methods to this process.
2. We provide a good communication media between the C&C user and the software developer. We organize and discipline this software development process through software engineering techniques, and finally we bring this software development process to the door step of the user.
3. We build windows into the automated functions so the user can see what he did when he automated his system and how it was done. These windows are achieved by various means working in consort, including man-machine interaction techniques and user oriented software documentation that is understandable and utilitarian for the user.
4. We give the user some special programming tools that allow him to modify programs in real time as his functional requirements change.
5. We develop cognitive aids and deliver knowledge based systems specifically tailored to higher order Command and Control Analysis and Decision functions.

The two primary technologies we look toward are Software Engineering and Knowledge-based Systems. The first addresses the total process of software system specification, design, programming, testing, documentation, maintenance, and modification. The second addresses the automation tools needed by the Command Center Staff to carry out those ill-defined tasks and swiftly react to unanticipated situations.

DISCIPLINING THE SOFTWARE PROGRAMMING ENVIRONMENT

In Munich, in 1968, the idea of putting rigor and discipline into the Software programming process was first publicly defined and introduced -- it was called Software Engineering. Since that time a revolution has taken place in the way we design, program and test software systems. You are all aware of such techniques as Structured Programming, Chief Programmer Teams, Programming Support Libraries, Design Languages, Top Down Design, Path Testers, Validators, Verifiers, and many more. The technology is well along and much is available today to finally control the programming process. Given a good system specification, a software system can be well defined, programmed, tested and transitioned to the user in such a condition that it can be well maintained and modified -- all done in a well managed manner. It has been done, and more of the software systems will be done this way -- it's just a question of time during which the training, management policies and procedures can catch up to the technology. The result of this process is a set of well defined, structured, and documented software that is capable of being understood by both the user and anyone who later comes along to modify the system.

This is a beginning to providing a window into the software so that the user can adapt the software as necessary. The disciplined programming environment now has to be made more directly available to the user, so the user will have direct access and control over the system programming teams. The programming environment consists of procedures, handbooks, and a computer which contains all the new software development tools accessible by these programming teams. The environment can be provided to the user by transitioning to the operational user the original software development support system so that it can be available for system maintenance and modification.

The one phase of this programming process that is not yet satisfactory is the front end or requirements definition phase where the user attempts to define his needs and communicate it to the programming staff, which then translates it into a software design. There are Requirements and Design Specification languages under development that do two things; (1) they provide a rigorous and standard way of describing the requirement and the system design, and (2) they provide an automated way to analyze both the requirement and the design for inconsistencies and deficiencies. Other approaches include better and faster means for simulating a proposed system modification for inspection by the user. A third approach, called automatic programming, is an attempt to go directly from the requirement as described in a special language to computer code with no intermediate design and programming phases. This latter area has been worked to some extent and experimental systems capable of automatically generating rather simple programs have been constructed. Work is directed at more efficient program synthesis by introducing both backtrack proof searches and interactive user intervention in the search process. Other work attempts to replace the complete resolution principle proof procedure with a more direct, though incomplete, Markov algorithm which has the additional goal of optimizing the resultant program on the basis of rules which contain knowledge of both programming structures and the domains of discourse (numbers, lists, etc.).

A second and more ambitious and flexible approach to system requirement and design is that of problem definition through general, interrogative-declarative man-machine discourse. It is the goal of some researchers to conduct such discourse in English. One of the most advanced discourse-based projects is at Stanford University. Independent advances in the mechanical processing of natural language have resulted from DARPA-sponsored research in robots and speech understanding. One of the most total approaches to this question was the automatic programming project at the MIT Computer Science Laboratory whose goal was to pass automatically from natural language discourse to a customized inventory control system. Work at Harvard is directed toward semiautomatic support in the experimental optimization of programs, including automatic (though, perhaps, user initiated) data restructuring.

Other approaches are problem statement via example, e.g., System for Business Automation (SBA), and problem statement by sample problem, e.g., University of Texas. SBA is basically an applications oriented programming system while the latter work is based on the automatic generation of programs by a theorem prover.

A current project under development at the Information Sciences Institute of the University of Southern California is the SAFE (Specifications Acquisition From Experts) system. The goal is to produce programs from semiformal specification, expressed in English, similar to those found in military acquisitions contracts. All of these approaches require further development.

With the complete implementation of software engineering technology, we would be in a position to modify the software systems on a timely basis in direct reaction to the user's needs. This means that we at least would have the flexibility and adaptability for the more routine and definable automated systems. At the same time Software Engineering applied to C² implies that the user/operator of the Command Center must treat his software the same way he manages his SOPs and Office Instructions. The software is his to help his organization do its job, it must be customized, documented, controlled, modified and most of all formalized in the way it is planned, implemented and used; Software Engineering does this for him.

COGNITIVE AIDS AND KNOWLEDGE BASED SYSTEMS

I would like to address the man-machine interaction area and associated cognitive aids. You have all heard of natural language query systems and the singular lack of success in achieving such a capability. In spite of this, the basic need is still to provide a communication vehicle which allows the human to phrase a question or pose a situation in his own natural language that provides the richness of such a language and requires little training. This language must be translatable to computer commands. Of course the richness of the natural language violates the rule of unambiguous input to a computer. The approach to this dilemma is to constrain the natural language, and to allow easy interaction with the computer so the erroneous computer response can be quickly viewed by the human and his request modified.

This is the way human-to-human communication occurs and I see no fault with this approach. Continual lexicographic research and experience with various query languages is going to make it possible to obtain what we want. But what we want and what the various staff officer levels and commanders want is going to be different until we observe closely the problems these users meet, and until we introduce the proper training and conditioning of these people. A whole new generation of people used to working at computer terminals, coupled with a better understanding of and visibility into the computer software system is going to relieve this. Of course research in voice input to computers will also help the problem definition phase.

The people who build query languages, front end processing languages, terminal oriented decision aids, etc., have got to observe closely in detail the problems users are having as they sit at the computer terminals. Except for routine functions as in reservation systems, banking, etc., little attention has been given to the human factors aspects--it isn't a research problem, it requires some good thinking and persistent hard work.

Given that we achieve satisfactory human-to-machine communication, what is being done about making the computer a more useful tool for the knowledge worker, the decision maker, the cognitive worker, or whatever you want to call that person who has to perform ill-defined military management and decision functions? First we can certainly give him all the latest technology that is available, including word processing, text editors, and text scanners, relational data management systems, personal file systems, electronic mail, computer conferencing, dynamic data base restructuring and on-line operations research tools. The challenge here is the engineering and tailoring of these aids for the specific applications. Again, here, the user requires control over and direct access to the programming development process and environment.

The R&D community is doing something with these standard tools to help this class of user. I quote from a recent Air Force Planning Guide which presented this well:

"Some of the activities at various Artificial Intelligence research centers are applicable to the needs for more knowledge based computer tools to aid in decision making in a C³ environment. These activities can be divided into four areas: Problem Solving, Information Integration, English Language Interaction, and Reasoning Explanation.

"Problem Solving. For a decision aid, the "problem" to be solved is to formulate options, i.e., sequences of actions, which satisfy the goals of the decision-maker in the current environment. Early AI work, especially that developed for game playing, viewed the problem solving process as a heuristic directed search using local information or knowledge to arrive at a solution through a vast solution space. Newer work emphasizes the view of problem solving as a "planning" process. In this process, the machine applies overall knowledge of the problem to plan a solution by defining a series of subgoals and then applies local knowledge to reduce the subgoals into a sequence of actions resulting in a solution.

"Work on the NOAH system at Stanford Research Institute uses the idea of hierarchical refinement. A plan is represented by a tree in which each descending level represents more detailed refinements of the subgoals. The subgoals in the plan are kept unordered until the interaction between each subgoal process is defined such that the sequence of subgoal accomplishments can be determined.

"Work on the PLASMA system at MIT uses the notion of an "island" to guide the planning process. An island is a step in the solution which the system knows must be present, thus greatly reducing the number of alternative solutions which would have to be considered. Other work at MIT uses an automatic programmer to debug the effects introduced by the interaction between independent subgoal solutions.

"All of the planning approaches to problem solving emphasize the use of knowledge about the problem to reduce the amount of search to arrive at a solution.

"Information Integration. Techniques for integrating diverse sources and levels of information have been developed as a result of ARPA funded work on continuous speech understanding. In order to understand an utterance, the speech system must integrate higher levels of information on pragmatics, semantics, syntax, and phonetics with the lower levels of information present in acoustic signal data.

"Work at Carnegie Mellon University is based on an elaboration of so-called production systems. The Carnegie Mellon University system consists of several independent knowledge sources containing rules which communicate through a common data structure called the "blackboard". Using situation-action rules, the current subgoals to be addressed are stored symbolically on the "blackboard" and any "knowledge" may execute a process and/or update the "blackboard." This type of control structure also allows for identifying the knowledge source with the best capability to address a particular subgoal of the system.

"Current work on complex data structures for representing and relating information is being done at XEROX Palo Alto Research Center and MIT. These data structures, called "frames," can be used to represent stereotyped objectives or events, making explicit the components and interaction between various elements.

"English Language Interaction. Graphical displays are currently used to present and summarize information; however, if the system is to communicate decision options as opposed to information, techniques are needed to communicate at a higher level. Recent advances in natural language understanding offer the possibility of communication in English.

"The advantage of using natural language is based on the system's ability to understand, e.g., that 'How many F-4s are available?' has the same meaning as 'Print the resource field of the aircraft record which has the name field equal to F-4.'

"Much of the current work in natural language communication is focused on understanding sentences in context. Efforts at Yale, and at the University of Maryland are focused at understanding utterances above the level of a single sentence. Recent attempts have been made to apply the RADC sponsored Rapidly Extensible Language (REL) development at Cal Tech to the problems of using English for data base retrieval.

"The University of Illinois is taking an engineering approach to language understanding by using a large number of "request templates" and pattern matching instead of a traditional parsing system. This system is especially interesting since it addresses the domain of data base retrieval of aircraft maintenance and flight information.

"Stanford Research Institute is currently building a natural language data base retrieval system for Navy Advanced Command and Control Architecture Testbed (ACCAT). The work at SRI uses an already existing data base management system, (The DATACOMPUTER) and attempts to translate English requests into the retrieval language of the underlying data base system.

"Reasoning Explanation. In the C³ environment, man is still the ultimate decision maker. Any useful system must be able to explain and justify its options in terms understood by the user of the system. A similar problem has been faced by AI researchers trying to produce automated aids for medical diagnosis. Since the physician is ultimately responsible for the patient, any useful diagnostic aid must not only present him with options but allow him to scrutinize and examine the method used by the system. The most advanced work has been done by the MYCIN group at Stanford University. The MYCIN system is able to explain the reasoning chain used in reaching a diagnosis. This explanatory ability is useful in four ways:

- "(1) As an educational tool, it helps novice users by demonstrating accepted methodology.
- "(2) As a justifying source, it helps to assure that the diagnosis and treatment is correct.
- "(3) As a debugging aid, it helps the expert user pinpoint where the system made an error.

"(4) As a knowledge screening source, it shows the physician information relevant to the case in question."

In spite of all this R&D one must recognize that experience at the terminal by the military user is the best way to obtain the visibility into the system and to devise his own problem solving techniques.

DISTRIBUTED DATA PROCESSING.

Given a high degree of automation, Distributed Data Processing is the technology needed to link all of this together into a cohesive system. Distributed Data Processing - What is it? It is a group (2 or more) of computer processors (or computer systems) coupled together to carry out a set of processes (functions) where a high degree of dependency among either the processors or the functions is required. The scope can range from two microprocessors sharing a limited process control function to a global linking of many large diverse computer systems sharing data and functions in a military or industrial command management system. The requirements, technical challenges, as well as the technical approaches vary widely over this broad range. The technical challenge in having two identical microprocessors share the results of two separate processes one running on each device is of an entirely different magnitude than the challenge posed by the interoperability among multinational command systems using different computer hardware and operating systems.

Distributed Systems differ in many ways:

The degree of coupling and dependency among the elements of a distributed system can vary greatly; some systems pose unusual requirements on the communication scheme used, others none at all; the number of separate units, even though simple in nature, that make up a distributed system, can pose major challenges if the number is very large; some systems operate in a completely decentralized mode, others with tight central control; some systems are highly redundant while others impose stringent reliability demands.

The Distributed System of interest in this paper is the one that links together the data processing elements that make up Surveillance, Intelligence, Command and Control. These are characterized by a respectable number of medium to large scale computers with a fairly large number of minicomputers and microprocessors as satellite processors, primarily for data input. All of these are separated geographically, utilize a variety of communications, perform independent and diverse functions and most importantly are computers from a variety of manufacturers and which utilize a variety of Operating Systems, many of which are tailor-made for the specific application.

There are several purposes for a Distributed System in this environment, the primary one being the need to transfer and access data. A secondary purpose is to increase the survivability of C-1 through backup and redundancy, and a third purpose is to allow the sharing of computer power during overload periods.

There are several levels of interaction or interoperability that might be required for the above purposes. The ultimate capability required, and the highest level of interaction, is the ability to transfer individual records of data among the machines along with the software modules that functionally operate on these individual records, all done in such a way that it would appear as if the Distributed System was one functional multi-programmed/multi-processor computer system. Such a capability is not technically feasible today, although there are instances of multi-program/multi-processor computers where the hardware is identical and a single operating system is used. Even here much remains to be done to improve the reliability and performance of such a computer. A much lower level of interactive capability and which I will call the second level is the ability to transfer whole files from one machine to another of different manufacture, so that the data can be operated on by the software process in the computer to which the data is transferred. This capability has been implemented on a case by case basis; recently a more universal solution to this file transfer requirement has been demonstrated through a DOD program called the National Software Works (NSW). There are several levels of interaction between the extremes and one must be careful to specify the level when describing a requirement or a capability in Distributed Systems.

The NSW Program has demonstrated the ability of a user at any terminal to request access to any host computer in the Distributed System and to utilize the software on that host for whatever purpose desired and to transfer the results of a process on one host to a file in a second host and then to initiate a process in the second host to operate on this file. All this would be done without having to learn the protocols, the job control language, and the file structure of any of the computers. The user interacts with the total system through a common language and all file transfers between machines are converted automatically for operation in the second machine. A network operating system called a Works Manager is used to control the assignment of host computers and their resources to a user, takes care of all accounting situations, and accomplishes all file conversions.

A Front End Processing System provides a universal transfer interface both between the user's terminal and the ARPANET and between the user and any host machines by providing a common protocol and job control language, and other functions. Software in the host machine called the Forman links the local operating system and the services of the host machine to the NSW System, without interfering with the functions of the local host operating system. Initially this capability allows a fairly low level of interaction mentioned above, namely the transfer of whole data files among different computer systems; access to those data files and their transfer is made easy and on a real time basis even for the first time case. There is as yet no capability to transfer software processes nor to access files at the record level. All of the above functions are controlled by the network operating system called a Works Manager; this may run on one or more of the host machines and operates in a noninterference mode with the local operating systems. The Front End processing can be accomplished either on a PDP 11/40 or in the host machine itself. The system is designed to be independent of the communications media and can be transferred from the ARPANET to AUTODIN II or other communications with a minimum amount of software development. This system is intended to be a universal design approach to the networking of dissimilar computer systems where at least a second level of interaction is required.

Other research and development is being performed on network operating systems and distributed data base systems which will allow a higher degree of interoperability. At this time development of such a capability appears to be of medium risk and it is expected that within 10 years a very high level of interaction or interoperability in a Distributed System will be operationally possible.

It should be pointed out that the technical ability in a computer science sense to achieve this high level interoperability requires a commensurate management capability and system architecture capability to take advantage of such technology. This must also be coupled with the ability to accomplish performance evaluation of various architectures in a C²I environment, so as to insure that the Distributed System Architecture can meet the operational requirements in a practical manner. This in fact is the most challenging R&D yet to be performed; namely, System Architecture Design and Evaluation. Equally important is the ability to analyze the operational requirements in terms of data flow and processing function assignments, coupled with the system reliability requirements.

During the next 20 years such distributed systems will extend themselves to the lowest unit level because of the advent of very large scale integration (VLSI). This has already manifested itself in terms of microprocessors which can be very inexpensive and provide local processing capability for interacting with a Distributed System. The advent of inexpensive computer hardware poses tremendous system architecture design problems, but holds out the hope of possibly substituting inexpensive hardware for some expensive software. By this I do not mean that the microprocessor will replace the software, although it will perform a software function; instead much of the supervisory or overhead software for time sharing systems may not be required in the era of cheap computer systems. Such highly decentralized processing may reduce the extent of functions handled by today's operating system software which is required today to make more efficient use of the fairly expensive large computer hardware. Of course redundancy and survivability requirements are also somewhat alleviated by inexpensive decentralized processing capability.

The nature of command and control and intelligence is such that a range of computer systems from the personal microprocessor to the large scale data base machines are going to be required in the foreseeable future. This, together with the fact that standard military computer architectures, such as standard instruction sets, if implemented at all will not impact on the military computer environment for C²I for a good number of years means that the capability to handle distributed processing on several size machines of different manufacture in a tactical environment is a prime C²I requirement.

Distributed Processing Systems in the ultimate sense of extreme interaction coupled with the very inexpensive digital hardware opens up opportunities and challenges that today stretch the imagination even more than the advent of time sharing did in 1965. We have gained a lot of practical experience in applying time sharing which I think is going to allow the military to do a much better job of taking advantage of this advancing computer technology with all its potential and limitations - I sincerely hope so.

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DISCUSSION

Question:

Would the speaker say a little bit more about automated programming.

Author's Reply

- (a) The term "automatic programming" as it relates to the problems of command control presents an initial dichotomy depending on the immediate goals of the user. On one hand we have those efforts aimed at reducing the time and cost of software production by automating part or all of the production process. On the other hand we have efforts directed toward producing systems capable of accessing distributed data bases and directly synthesizing the knowledge retrieved in response to a natural language query or command. No software for external use is provided in this case: the goal of the system is to produce real-time answers.
- (b) Careful scrutiny of the methods of software production yields three basic processes that a system may utilize to obtain the required program: (1) The system can take a high level language program or a program description in a suitable formal specification language and directly convert this to the target program. (2) Using formal input-output specifications the system can attempt an exhaustive enumeration of the set of all proofs until an acceptable answer is found. (3) The system may be able to build an acceptable program by modifying and/or combining known (and suitable documented) programs that reside in a programming data base. Short term payoffs for narrowly defined applications domains in command and control are envisioned here.
- (c) The other view of automatic programming has led recently to running systems with impressive capabilities. The LADDER system of E.Sacerdoti at SRI responds to natural language queries and commands. Working with a large naval data base, it performs a complicated synthesis of the results of its data search in arriving at the answer. PROSPECTOR, also of SRI under P.Hart, is a rule-based system that serves as an expert diagnostician for the field geologist in his search for ore. In duplicating the responses of experts in the field in question, such systems are currently operating at levels beyond the average practitioner.

Question:

In your printed paper you have stated that no one understands the decision process associated with command and control. It seems to me that this is for the moment a stumbling block in the extensive use of computers in the C² process? I am just wondering if even with a window into the automated C&C process it will be possible to overcome this difficulty? What do you mean by window?

Author's Reply

- (a) The decision process in command and control cannot be defined or described so that one can program a computer to either perform the process or to explicitly provide the proper information to the human decision maker by means of an a priori computer program. This is because the human is reacting to an unanticipated situation which involves different information and different criteria for a decision. Yet there are quite a few anticipated situations that are handled by computer programs that retrieve previously specified information, process it and display it as specified.
- (b) If the staff officer in a C² Center understands why a particular program was written, the nature of the data base it operates on, and the processes it performs, then this program might be able to be used to obtain and display the information needed for this new situation. The staff officer will have to make some intelligent changes in the way he uses this program and interprets the displayed data. He can do this only if he can appreciate how the computer system is handling his request.
- (c) The window I am referring to is the capability of the C² staff officer to modify or tailor the existing computer programs and procedures so that he can continue to carry out his decision process. We still don't understand the decision process used by the staff officer when he encounters a new situation, but we give him the flexibility and tools to allow him to use and adapt the computer system for his purposes.

SOFTWARE FOR ROYAL NETHERLANDS NAVY.

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SUMMARY

This paper deals with the experience gained by the in-house development of real-time software for large shipborne command and control systems for the Royal Netherlands Navy. The intention is to demonstrate the RNLN's "both feet-on-the-deck approach" to the problem of finding a path through the software engineering jungle followed by the RNLN. To simplify things and try to find out real trends is especially important in software engineering, for there seems to be more inventiveness in introducing new words and phrases than real new ideas. It is the authors opinion that software engineering itself progressed only slowly over the past 10 years, but since the famous Garmisch (1968, (3)) and Rome (1969, (4)) conferences there is an exponentially increasing interest in software engineering and related problems. Well defined and solvable problems have been over-treated, but a few, from the user/software-producer point of view more important but ill-defined and perhaps unsolvable problems, have received little attention. Software engineering for command and control systems is a part most times the major part, of the total project's system engineering. This is especially true in the RNLN.

1. INTRODUCTION

Over the years, an overwhelming amount of paper, books etc. on problems in software is published. This clearly demonstrates that software although it is no longer "the art of programming", is still no "industrial product" with established quality standards and production quantities. The enormous sums of money spent on software and the increasing importance of software, requires a continuous effort from the producers to obtain optimum software production techniques. Indeed the interest in software engineering matters is increasing, the amount of papers produced is increasing even faster and software engineering has become a jungle from which is difficult to get out. No solutions have yet been found for overcoming the high cost of software, but what is more: there is not even a real indication of a breakthrough. The CAWCS has been in this jungle from its inception in 1968, and has been confronted with all the difficulties in this ill-defined area. We have not attempted to find special case solutions to problems, but have always tried to see things simply as possible. By doing so we have been able to specify, design, produce and test software for large command and control systems in-time, in-budget and with the required performance.

In para 2 an oversimplified review of major software-engineering trends is given. The point of view, it has to be explicitly stated, is CAWCS, thus the very practical producer/software-engineering point of view. Two recent publications (18, 34) are offering excellent starts for tutorial and/or further detailed reading.

In para 3 the practical case of the CAWCS is considered as a typical example. Only a few characteristic points will be highlighted. It is believed that every programming centre, or programming project group etc. has typical characteristics, thus experiences cannot simply be transferred.

In para 4 two typical problem areas will be discussed, which are to the authors knowledge not yet sufficiently solved, but form the achilles-heel of the big software projects of the near future.

2. SOFTWARE ENGINEERING TRENDS

2.1. Headlines of the past.

"In the beginning was SAGE"

J. Leth-Espensen. (1).

"Programs do not acquire bugs as people do germs

-just by hanging around other buggy programs.

They acquire bugs only by having programmers insert them".

Harlan D. Mills.

After the famous Von Neumann invention to not only store data and variables but also programs ("stored program digital computers"), the program flow inherently got a flexibility unknown until that time. The programming job was born, software became a word and the devil became a new face: bugs.

In the late '50's the first attempt to increase programming speed and limit the number of bugs was to let the new machines do their own administration: assemblers and higher order languages were born. Capability, compatibility, transportability etc. became main topics and assemblers/languages became a high technology engineering (1) (3), (4). Assemblers/language are of tremendous technical/commercial importance and have over the years proved to be very adaptive in following the programmers needs. Assembler/languages made the opening into wide-spread use of computerbased systems and there is still a remarkable evolution (10), (11).

In the early '60's it became clear that for large programs the design was more the weak part than coding itself. This led to program and data segments, later modules, controlled by executives/schedulers and organised around a compool (2). Techniques now known as: top-down, documentation tree, stepwise refinement, structured: coding-programming-design-walkthrough-approach, modular decomposition, matrix-organisation, chief programmer team etc. have been explored and shown to be effective by those responsible for the early big and difficult projects. Everybody was smiling and proud to be working in difficult projects, but was not telling his neighbours about his principal problems!

In the end '60's however the problems started to be discussed in broader spectrum, mainly due to the two trendsetting conferences on software-engineering. The conference proceeding material (3) (4) is nearly unchanged valid today and is still a MUST-reading for every software engineer! At the same time the buyers, e.g. US DoD, started to tackle the problems of high cost, late delivery, unreliability and undue complexity of the software from their side by requiring adequate procurement and control documentation (31) (32). The famous WS8506 specification ("documentation tree") soon became known as a very helpful guide for software managers to set up and control their own projects, being complementary to the other software techniques (special to top-down and structured-).

In the '70's nothing really new happened. There came a lot of refinements and a lot of new words. The main technology is still based on straight forward common sense thinking (top-down, structured-) and writing (doc. tree), and mankind demonstrated the

success in hundreds of large projects. Some new aspects are covered or more seriously treated: e.g. testing, certification, quality control (7) (8) (24) intellectual ownership (9) and the known techniques are being applied to new fields (23). Psychologists analyzed the man behind the programmer (27) (28); interesting, perhaps important, but not solving any engineering problem. The most important however is the much, much, much wider understanding of the existing problems and the related interest in the available techniques (13) (14) (15) (16) (17) (18) (19) (29) (30) (34) (35).

2.2. Headline of the future.

"I would add as a corollary that large real-time programs require new tools in order to handle the production task adequately".

James H. Burrows, (2).

Currently software engineering is widening its scope but there is, in the authors opinion, no trend toward a breakthrough.

One of the major reasons is the ever increasing speed of hardware development in which in a linear increasing time-scale the packing densities and processing speed increases exponential while prices decrease exponential. This will not end before the actual physical borders are reached. This is estimated to be somewhere around 1985. Multi-computer system, microprocessor controlled intelligent peripherals, distributed databases, computer networks, no-limit memory space etc. etc. will keep off software/systems engineers from thinking of software-engineering itself.

One trend has been visible already for years and will be increasingly important: SYSTEM ENGINEERING becomes SOFTWARE ENGINEERING. More and more specially designed, and thus expensive, hardware will be replaced by cheap but powerful processors. A lot of hardware engineering effort will no longer be necessary, thus making hardware cheaper, for "this will be done by software". Variety in types will become exclusively variety in software to keep the price of main-production hardware low. The hardware-software cost ratio for a project will aggressively demand cheaper software. Where is the new software technology?

A second trend is the decreasing influence of defense systems projects in data processing development. In the hardware field, the defense systems are already starting to follow the commercial industry (12) and the same for software is already visible (11). Costs is a good reason to go in this direction for the time being, but the high inertia of industry in the direction of cheap mass-products does not necessarily parallel the governments need for a few extremely complex systems. Where will the new software technology for complex defense systems come from?

3. THE CAWCS, A CASE STORY

"Among programmers, there is a certain mystique - a certain waving of the hands which takes place whenever one tries to probe the manner in which programming is done. Programming is not done in a certain way, they say, it is just done. Either you can program or you cannot. Some have it; some don't".

Gerald M. Weinberg (28).

3.1. Brief survey, task.

The CAWCS started its operation in early 1967, not accidentally in the same period that software engineering became a discussion subject. The minister of defense specified the task of the CAWCS as (simplified):

- a. (In cooperation with the MOD procuring agencies) to coordinate projects on command, control and weapon systems, with specific concern for problem analysis, determination of configuration, setting of priorities and planning.
- b. To do system and program analysis and design for these systems.
- c. To produce and test software for these systems.
- d. To produce systems level documentation for these systems as operational instruction for the users.
- e. To maintain the software for these systems.
- f. To be the specifying and controlling agency for software produced by third parties.
- e. To do a few less important tasks.

This is really more than just making software!

The CAWCS started with 5 people and today there are about 100; little future growth is envisaged. The CAWCS started with one 120 manyear job and is currently involved in three major projects of roughly 70 manyears each in directly assigned personnel. The non-directly involved personnel, e.g. administration, typist, computeroperators/maintainers, general management etc., constitute an overhead of about 100%. The average projecttime is about 5 years.

3.2. Personnel.

The explosive relative growth of personnel is shown in figure 1.

The average new programmer comes in at about age 20 with no experience in dataprocessing and no special dataprocessing education. There is no typical background but the levels vary from highschool to Msc and specialisation from nothing to mathematics, physics, mechanical engineering, merchant marine officers etc. The know-how in accumulated years is shown in figure 2. Each year the average age (now 30) increases by about 0.8 years. About 50% of the personnel is military, the rest civil service. A typical problem in a growing government organisation (at least in the Netherlands) is the difficulty to get the right people in time.

3.3. Organisation.

The organisational chart is shown in figure 3.

Department 1 consists of 10 naval officers, from all operational disciplines. There is no further internal organisation.

Department 2 contains the directly project involved people (about 60). The internal organisation is havily influenced by the few experienced people and by the few big projects. It is mainly a project organisation, but there are some matrix-aspects. A typical aspect in this project organisation is the test and integration group. It is a well defined, separate group, but operating under responsibility of the projectleader.

The internal organisation of the departments 3 and 4 are of no importance for this paper.

Organisation, and how to tackle a project has proven to be an evolutionary process, and is a continual point of discussion.

3.4. Software engineering.

The CAWCS is continuously reviewing and with an open mind following various software engineering "innovations", but discussions are mainly very practical oriented and based on "boerenverstand" (Dutch version of: common sense).

The CAWCS has found a few techniques very successful and thus helpful (figure 4):

- * WS8506. Thus a documentation tree. CAWCS internal documentation system differs only a little from the official specification as the CAWCS is its own procuring agency! WS8506 has shown to be extremely helpful to CAWCS, especially because it stresses structural thinking on the various levels of documentation. A documentation tree like WS8506 clearly distinguishes various production and documentation steps and clearly separates testing from program specification, design and coding. It not only enforces top-down design and stepwise refinement, but it makes visible the various production steps. It proved to be easy to learn and use. (figure 5, simplified WS8506).

Another important documentation tool is STOP (33).

This documentation and material presentation method helped much in firstly making systems level documentation for the operational user and secondly in proper understanding of the operational features by this user. It helped to introduce the systems smoothly.

- * JOVIAL (J3). Certainly not the latest language, perhaps not the best on this moment. It was certainly one of the best when we purchased/produced the compiler. It is really a high-level-language (HOL, higher order language) and it still is one of the best. But by far the most important characteristics are that the language over the years proved to be good enough and what is even more important: it is our standard language.

- * Manmonth, or more generally: manning.

The aspect personnel is not too often considered an aspect of software engineering, but at CAWCS a lot of time is spent getting the right person to the right place. And that's the best, for a couple of reasons. Generally production time decreases when the number of assigned personnel increases. (constant number of manmonth). When there are however too less persons the project runs unmanageable long, when there are too many persons the project becomes unmanageable complex. We found the optimum between 10 and 20 programmers.

A related problem is planning.

CAWCS finds it most helpful to start a project slowly with just a very few carefully selected analysts/programmers and then to increase the number of assigned people as required; preferably not more than 20 people directly assigned to a project. This policy seems to delay the project about one year, but will save a considerable amount of many years. In fact a short planned delay is introduced at the very start of a project to assure enough sophistication in e.g. system specification and design and to assure project delivery at the planned time. ("Why seems there always to be time to do a job again and again, but never time to do it properly from the beginning?"). CAWCS has never been late in delivering software incl. documentation!

A third aspect to manning is the package of total-know-how available in one centre. In department 1 (figure 3) all and the latest operational/tactical know-how is concentrated and ready for direct consult, discussion and confrontation. In department 2 all systems, hardware and software know-how is concentrated. In all stages of the projects and on all levels in the organisation these two major departments work strongly together.

- * System engineering. CAWCS considers it very helpful to have a (shared) position in system engineering (task a). This is considered to be the single most important contribution to the success of software making. The determination of the configuration, the setting of priorities and the planning can, to a certain amount, be optimised from the software point of view. This has the inherent pro's of: lesser system engineering risks, better optimised systems, smoother planning etc. Software-conscious hardware!

As the CAWCS plays an important role in RNLN system engineering, hardware standadization could be effected. This eliminated the need for more types programming centre computers, languages etc, and thus greatly eases software engineering and enhances the programming centre's efficiency. For the CAWCS is software procuring agency and mainfacturer in one hand, it is possible to write the final SW specification when the project is already started. This considerably saves time and gaines quality. This time can be consumed in the already mentioned low profile start. Also important is that the system engineers are in direct and daily contact with operational users (customers).

3.5. Some results.

In figure 9 the absolute production speed are given for the four DAISY's (digital automated information processing systems) that finished their production. It concerns direct assigned personnel, and includes the system engineering activities. The CAWCS does not consider this high production speed, but it is not clear how to enhance the speed. The four projects were all delivered on time and within budget. The same has to be applicable for the current projects. When not only the new code, but all the produced code is accounted for, the asterix' and dotted line applies. Figure 10, top, gives the SW-cost per ship in relation to the total number of ships. There is a sharp decrease in cost if a few ships became a few more, and only a slight decrease if many ships are increased by a number. Thus especially for ships classes with a (very) few ships, software standardization with related ships is imperative! Standardization for the four types of DAISY into one DAISY-FAMILY considerably reduced the SW cost in the RNLN, not only for the initial cost, but even more impressive during the life cycle maintenance! (fig. 10, bottom).

4. DISCUSSION.

In the author's opinion there are two areas of software/system engineering which are still weak. Both are ill-defined areas, both are more or less covered in literature, but a clear overview still does not exist.

4.1. Functional performance.

Documents as "system functional description" or "system performance specification" are often discussed between tactical data systems specialists. Everybody has his personal ideas, and there is a lot of common feeling about such a document and the necessity for it. But there is little known about the relations between the system components, hardware, software, menware and procedures.

No systems-engineering technique is known that tells the optimum balance between the system components (hardware, software, man-ware, procedures) in order to achieve

FOR A GIVEN AMOUNT OF MONEY THE MAXIMUM GUARANTEED OPERATIONAL/FUNCTIONAL PERFORMANCE, AND WICH OPTIMUM VAN BE DEMONSTRATED.

A lot of work e.g. on system specifying languages is already done, but the creative operational/functions areas are becoming so complex that there is a strong need for a systematic approach. (figure 11).

4.2. Quality assurance in systems.

Quality assurance is a well known item, especially in military equipment, and a lot of work on quality assurance on software is already done. But NATO did not start before 1978 with the first committee on software quality assurance! On the systems side of software there is a big gap: What are objective criteria? Can they be measured and reproduced? Is in systems, whose performance rely mainly on software, a functional software test suffucient to measure the performance?

To find tools to adequately ASSURE us that software/systems have a garanteed performance is imperative for the early '80's.

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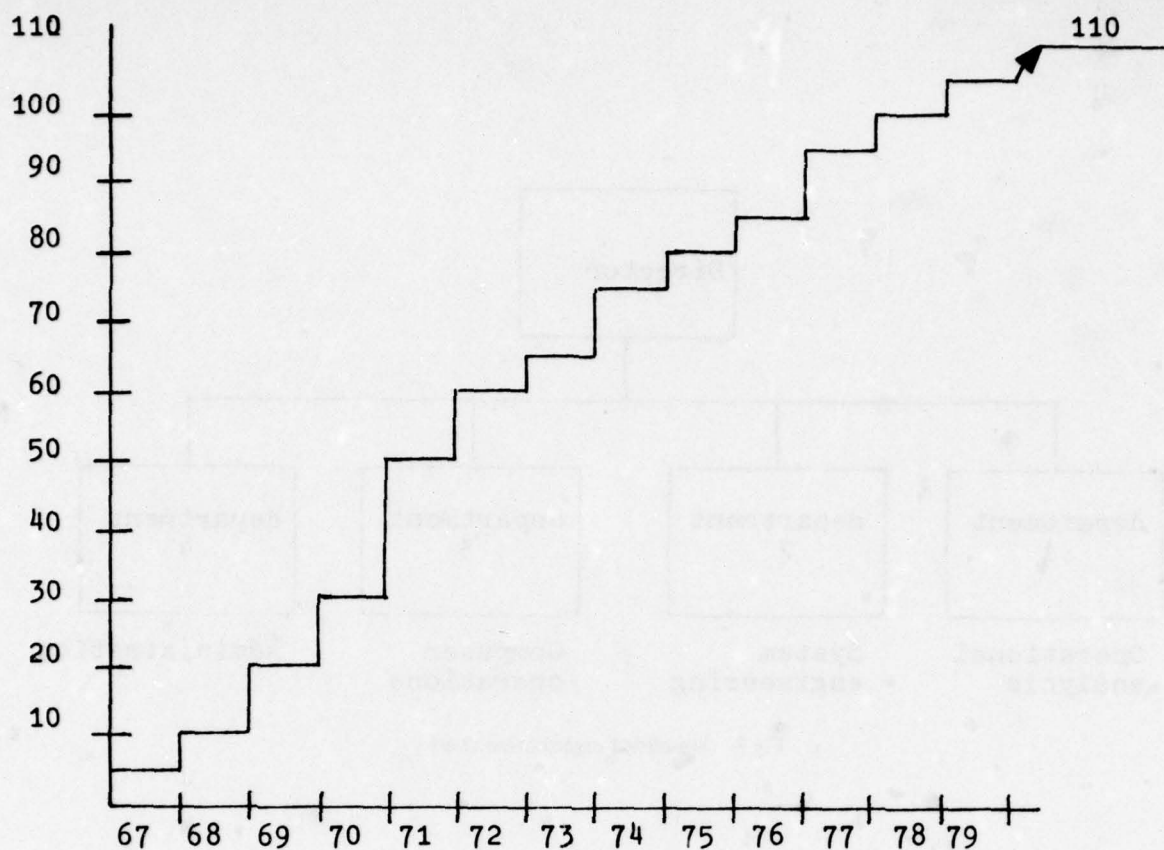


Fig.1 Growth of personnel

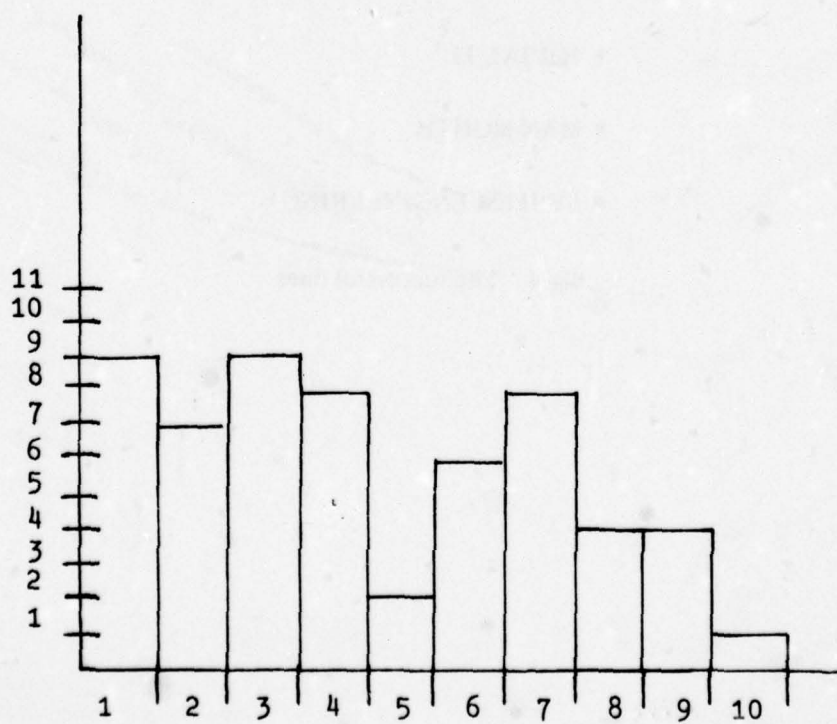


Fig.2 Know-how in man years of direct personnel

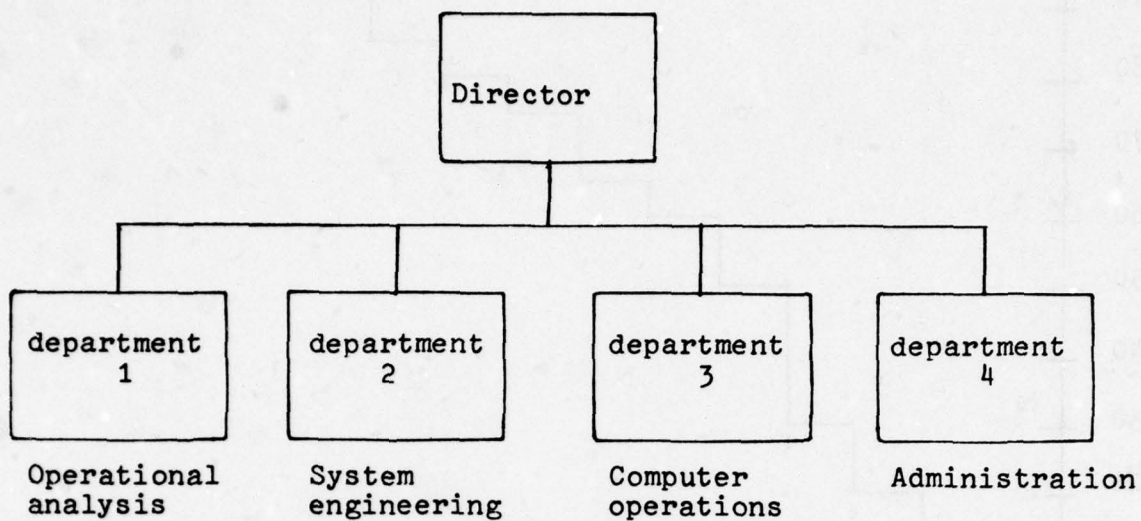


Fig.3 Simplified organisation chart

- * WS 8506
- * JGVIAL J3
- * MAN-MONTH
- * SYSTEM ENGINEERING

Fig.4 The successful ones

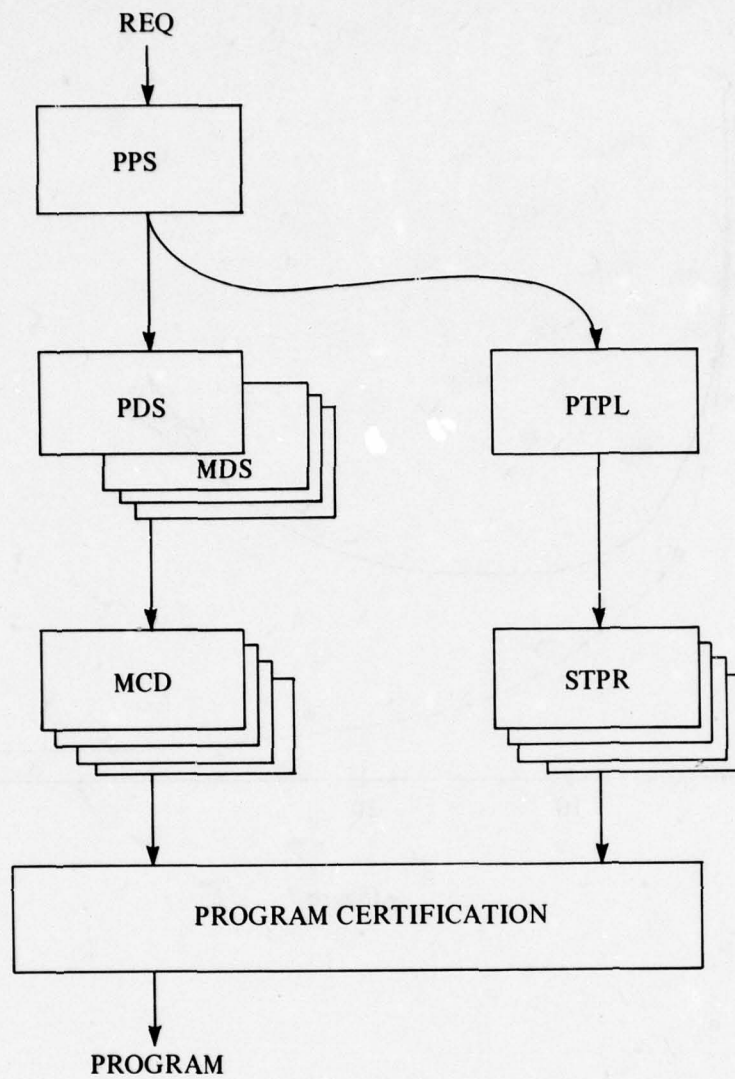


Fig.5 WS 8506

- * HOL
- * GOOD ENOUGH (τ, η)
- * STANDARD

Fig.6 JOVIAL J3

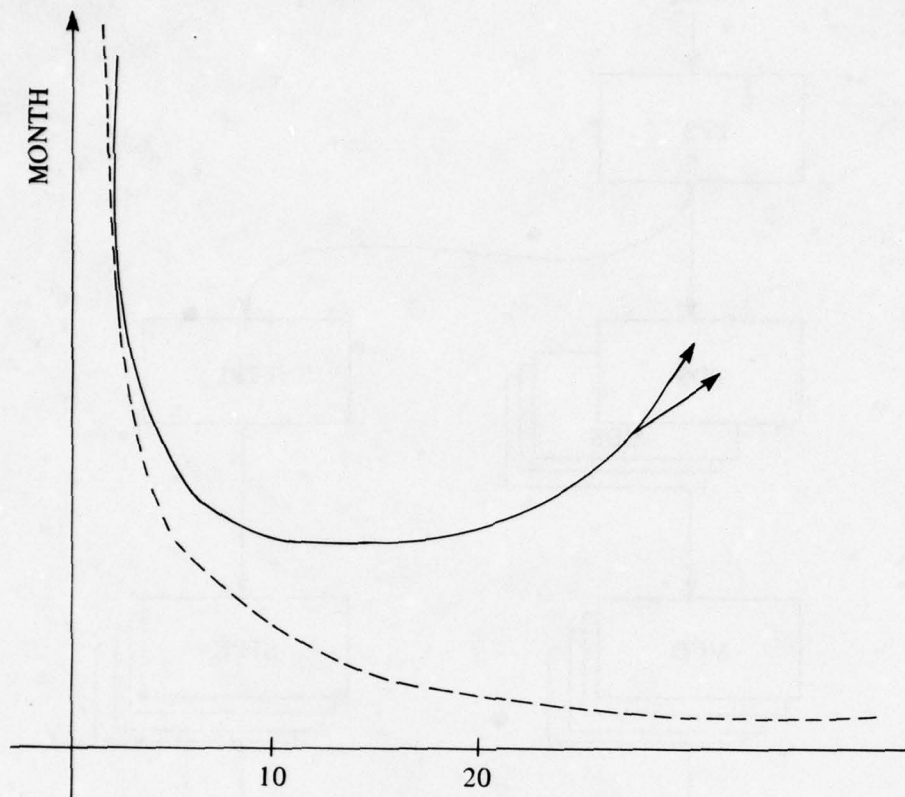


Figure 7

- * SOFTWARE KIND HARDWARE
- * HARDWARE STANDARDIZATION
- * "IN PROJECT" SW-SPEC-WRITING
- * LOW PROFILE START

Fig.8 System engineering

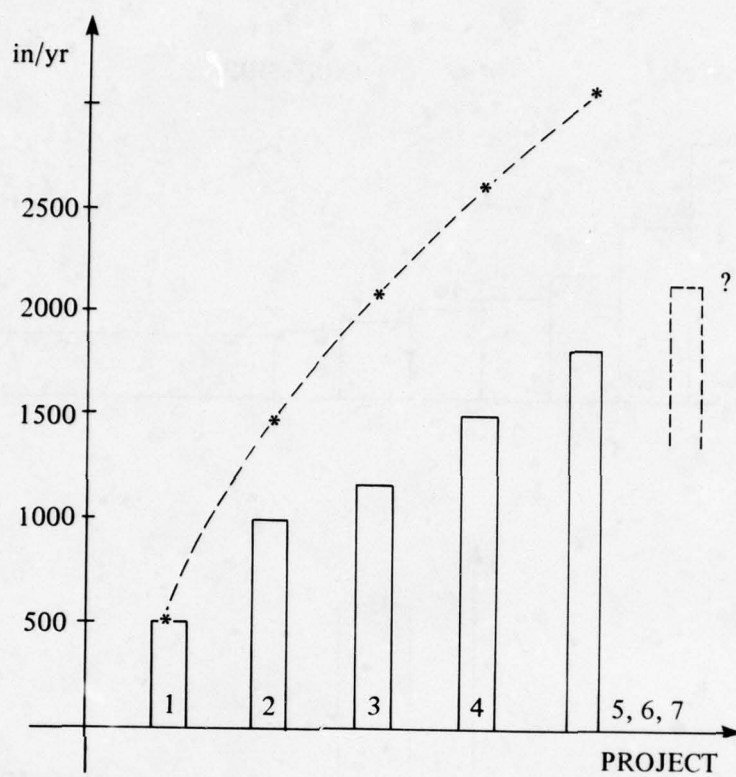


Figure 9

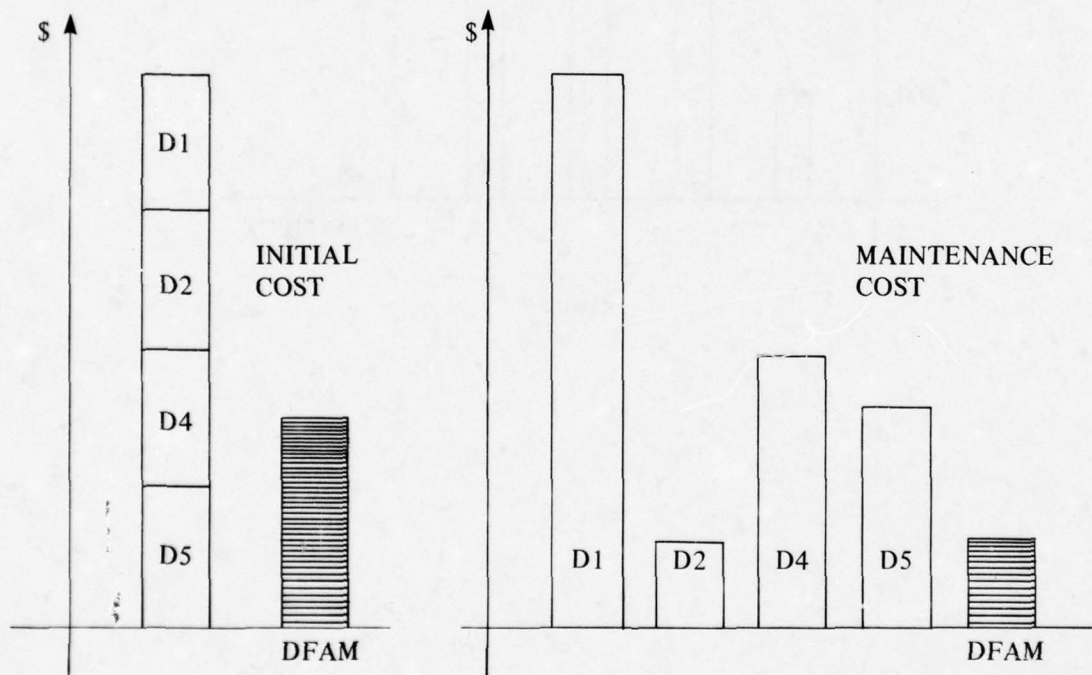
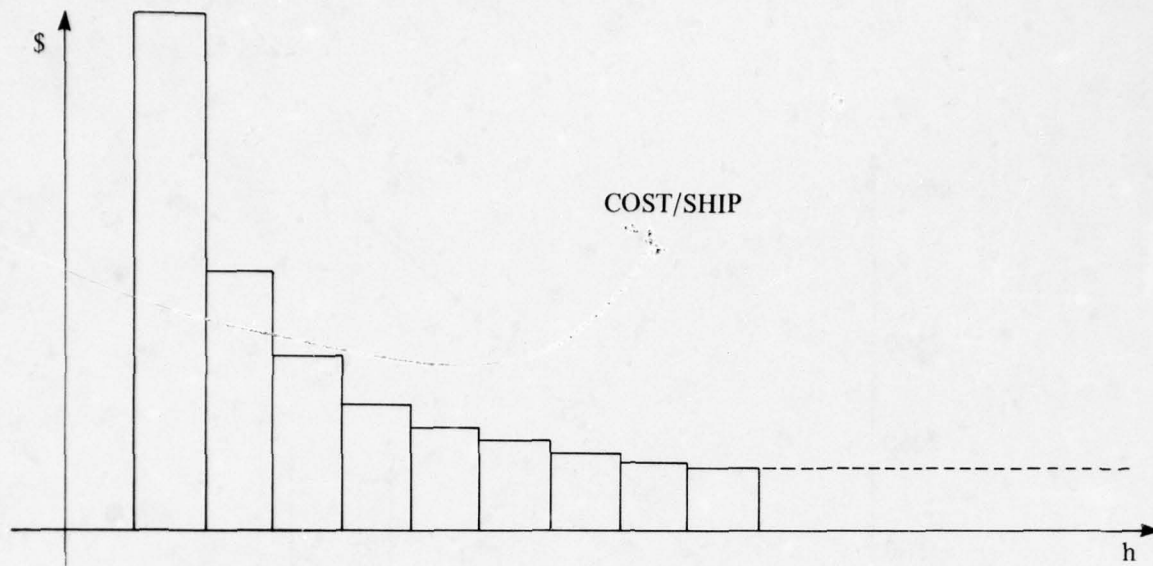


Fig.10 Typical software costs

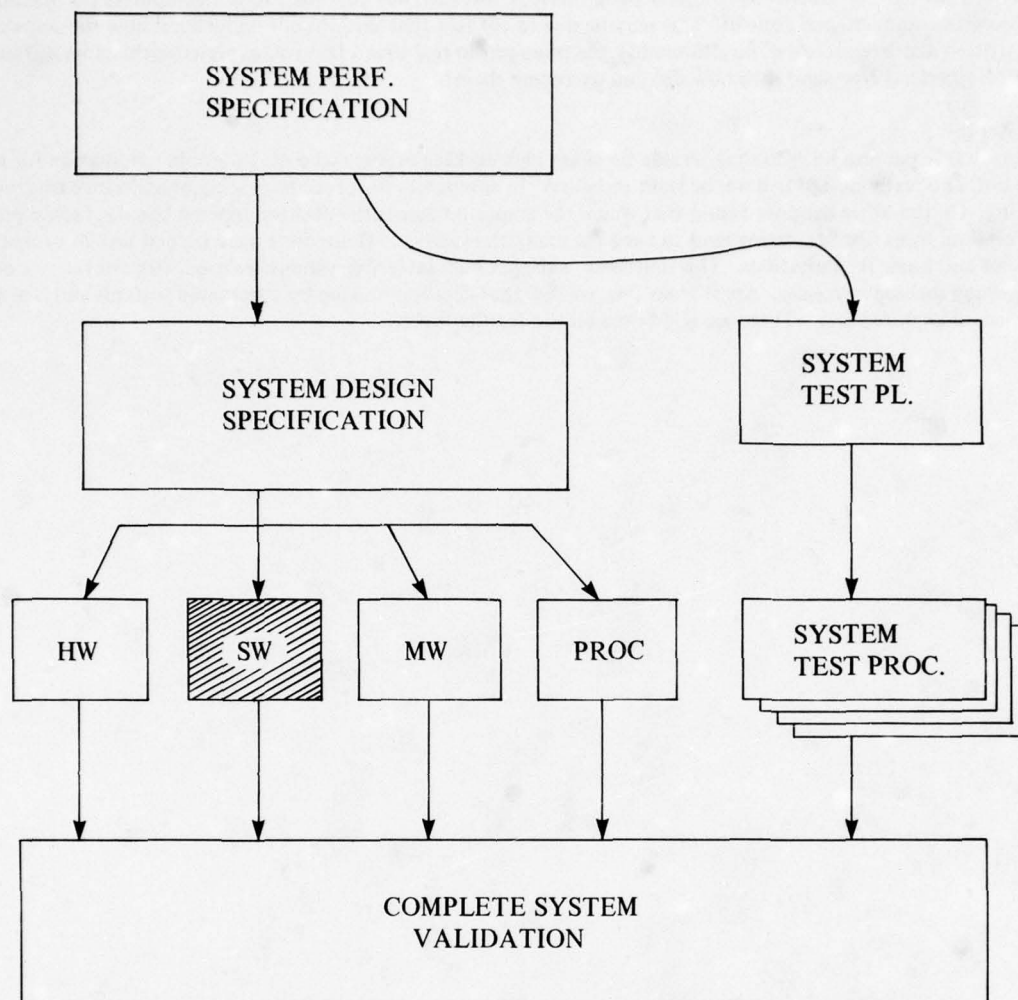


Figure 11

DISCUSSION

Brault

Yesterday Mr Barnum stated that military people at high level are very reluctant to use computers for making decisions in command and control. This may be due to the fact that they do not understand how the software was written and have no capability to modify the programs in real time. Did you experience the same difficulties in the Netherland Navy and if so how did you overcome them?

Author's Reply

The answer is yes and no. On the one side there are high ranking officers who do believe in automation for routine jobs but who really do not believe, or want to believe, in computers for decision making or assistance to decision making. On the other hand we found that where the computer assists the decision making based on some pre-assumption, users of the systems tend to heed the computers advice. These users were trained well in using the systems and knew its limitations. This illustrates well that high integrity systems are used with confidence even in decision making processes. Apart from this, we feel that decision making by automated systems still is a weakly defined, unexplored area. There are good possibilities for the future.

RESOURCE ANALYSIS FOR DATA-PROCESSING SOFTWARE

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SUMMARY

This paper summarizes recent work sponsored by NASA and the US Air Force to develop life-cycle cost relationships for data processing software. The primary approach has been to develop statistical relationships based upon actual experience on weapons and space programs. Cost-estimating relationships (CERs) are presented for major phases of the software life cycle, and for major variations in software characteristics and acquisition-management concepts.

Specific impacts on software cost are discussed for (1) the effects of hardware capacity-constraints, (2) the effects of execution-time constraints, (3) choice of language type, and (4) use of structured programming procedures. Also discussed is ongoing work to examine the interrelationships among the life-cycle phases, together with their influence on software costs.

1. INTRODUCTION

There is growing recognition that the development and use of computer software requires a major commitment of resources. The costs of developing software for individual large-scale military and space systems have ranged upward from tens of millions of dollars to nearly a hundred million dollars for programs such as Safeguard or Apollo. Many observers have noted that software costs now far exceed associated hardware development.

The analysis of software poses a number of challenges that stem from fundamental distinctions between hardware and software. Among these are the following:

- Most hardware elements can be associated directly with a single functional purpose (detect airplanes, transmit data, etc.). Software, on the other hand, often serves an integrating role, tying together the individual functions of a number of hardware elements--thus complicating the problem of describing the functional "output" of software development (i.e., what the software does).*
- In addition to problems of defining the functional output of a software development program, it is also comparatively difficult to define and measure its more directly described "physical" output. Number of lines of code is one measure, but this can be ambiguous, with differences in source versus object code together with questions such as how much of the code is new programming, how much was developed but not delivered, whether COMMENT cards are included in the line count, etc.
- Another significant problem with software cost analysis grows out of the fact that actual software costs have not been recorded in detail comparable to that available for hardware programs. In many cost reports for weapon systems, the hardware costs will be itemized in considerable detail, while all the software expenditures are reported as a single-line item.

In spite of these difficulties, there has been significant progress in the development of cost analysis procedures and specific quantitative cost estimating relationships (CERs) for software. This paper discusses elements of this work which we have carried out in studies sponsored primarily by the US Air Force and by NASA.

While I speak of "significant progress," the fact remains that cost analysis of software programs is still an uncertain process. The purpose of this paper is to present an interim report of the results of recent work towards an ultimate goal of improving techniques for predicting the costs of new software projects.

2 COST ANALYSIS OF COMPUTER SOFTWARE

The basic objectives of our software cost analyses have been twofold:

- Develop comprehensive life-cycle CERs so that all costs associated with software development and use may be taken into account, and
- Develop CERs which are sufficiently detailed to permit choices among the major technical and management characteristics of software projects.

Another goal of our studies has been the development of CERs which can be used at early stages in the acquisition life cycle. Thus, the estimating relationships should not be based upon detailed design descriptors which can be identified only after extensive design and coding.

* The ultimate goal of the resource-analysis model is to relate functional output (e.g., for a radar system, this might include number of targets, data rate, airspace volume, etc.) to resource inputs (e.g., cost and time). This has been accomplished with some success for many hardware elements. However, developing similar descriptors for the functional output of software has proven to be more difficult.

Our basic approach to the analysis of software costs is parametric cost analysis. The parametric method involves the analysis of related historical "actuals" in order to infer the costs of future systems, equipment, or software. Techniques of statistical inference and engineering analysis are part of the overall method. Costs appear as dependent variables in estimating equations, with the independent variables being selected performance, design, or "management" descriptors.*

The following paragraphs address:

- Identification of Software Cost Determinants
- Estimation of Software Costs by Development Phase
- Consideration of Interrelationships Among Life-cycle Phases

2.1 Identification of Software Cost Determinants

As part of our software studies we have carefully surveyed the literature on software cost analysis (see, e.g., BROOKS, F., 1975, CLAPP, J. A., 1976, DEVENNY, T. J., 1976, GEHRING, P.F., 1976, MORIN, L., 1973, PIETRASANTA, A. M., 1970, Trainer, W.L., 1974 and US AIR FORCE, 1974), and discussed software costs with knowledgeable personnel in government and industry. These sources have employed a great variety of cost-determinants, however those which we have found to be most significant include (1) size, (2) execution-time constraints, (3) memory-capacity constraints, (4) language, and (5) management approach.

Size of the software is a primary measure of output, and is an obvious cost determinant. However, accounting for the number of lines of code raises a number of issues which are addressed subsequently.

A cost-size relationship must then be modified by a number of other considerations. Among the most significant are any execution-time and memory-capacity constraints that may be imposed upon the programmer. "Real-time" is a descriptor generally used to indicate time-constrained programs (although this is not completely accurate). Many applications programs are time-constrained.

Capacity constraints are a "fact of life" for most military and space avionics systems. Each of these determinants has been addressed in our studies.

Other significant cost determinants include the choice of language (the basic choice being between assembly language and a higher order language, or HOL), and a choice of management techniques. This latter choice includes the variety of management procedures which is widely discussed under the title of "Structured Programming."

2.2 Estimating Software Costs by Development Phase

The following paragraphs summarize the CERs we have developed for the various phases of the software life cycle. These equations are written for a specific set of conditions, namely:

1. All code is written in assembly language.
2. The code is largely time-constrained (or "real-time" code).
3. The code is not developed under Structured Programming procedures

Variations from these conditions are examined in Sec. 2.3.

The first phase we have identified for the software acquisition process is Analysis. However, to a large degree Analysis is not a software activity, per se. Included in the Analysis phase is development of the basic mathematics of the system process (e.g., the equations of motion for a body in orbit around an oblate spheroid with an irregular gravitational field). Thus the effort required is strongly influenced by the state of knowledge in particular scientific and engineering fields--and the degree to which some new system will extend that knowledge. The complexities of this process are not directly related to the complexities of coding the resultant algorithms. Thus, Analysis will remain largely non-parametrically related to characteristics of the software. We did compile data which included the software personnel associated with Analysis and Design. Consequently, we have combined these two phases as far as estimating the effort required of software personnel.

Analysis and Design. In the course of our software cost studies we obtained data from the Boeing Company, from a GRC project and other industry sources, and from a study of the Apollo program (RANKIN, D., 1972). Using these data we developed the CER shown graphically in Fig. 1.

Coding. Using the same data sources noted in the preceding paragraph, we derived a CER for the Coding phase as shown in Fig. 2.

Testing. A corresponding estimating relationship for testing is shown in Fig. 3.

*The other basic approach to cost estimation is the "Industrial Engineering" approach, in which very detailed assessments of labor, material, and unit costs are made. These are then summed to develop total costs. This approach relies upon specific design details which are generally not available during early phases of the system life cycle.

Maintenance. A set of data about this phase of the software life cycle was available in the ADPREP.* This data permits an assessment to be made of the number of maintenance staff required as a function of the amount of code and the language used. The resulting CERs are shown graphically in Fig. 4. It is important to note the relatively poor fit (i.e., the equations do not account for even 50 percent of the inherent variance in the sample). However, more recent data generally corroborate these findings.

2.3 Identification of Additional Cost Relationships

The preceding section set forth cost-estimating relationships for the development of software which is (1) coded in assembly language, (2) developed under conditions of execution-time constraints, and (3) not developed under the procedures of "Structured Programming." This section discusses cost relationships for variations from each of these conditions.

Assembly Language Versus Higher Order Language. The fundamental distinction in software language is between (1) assembly language, or machine-oriented language, and (2) higher order language (HOL). We examined several sets of data to develop quantitative assessments of language as a cost determinant. The choice of language should have little effect upon the activities of Analysis and Design; these activities are not concerned with specific languages. Subsequent phases, however, should be directly affected by the choice of language. However, we do not have direct data which includes cost by phase and variations in language. The ADPREP data, which does include variations in language, is for total development.

Using the ADPREP data, several relationships were examined. The statistics for the resulting estimating equations are unimpressive, but they do underscore the influence of HOL upon the cost of software development. The coefficients of the language term indicate that assembly language programs are approximately two to five times more expensive to develop per object instruction.

Brooks and others indicate that the benefits of HOLs extend beyond software development. The use of HOLs "will result in more easily maintained software, more readily changed software, more reliable code..." (US AIR FORCE, 1974). The ADPREP data also include information about maintenance staffing for various programs. Figure 4 indicates the difference in maintenance staffing for programs written in assembly language versus HOL. Here again, the two-to-five-fold increase in assembly language cost is applicable.

Time-Constrained Programming. It is difficult to develop software in which prescribed functions must be executed within stringent time constraints. The organization of memory storage and the sequencing of instructions and subroutines is much more complex. Wolverton observed that "the cost of producing real-time (or time-critical) software is three times more costly than non-real-time software." (WOLVERTON, 1974).

From other data, the cost difference is not so clearly established. Figure 5 is a graph showing the data from PARMIS and ADPREP, together with data obtained from Boeing and other sources. The same (approximately three-to-one) ratio can be seen. However, there is considerable variability in the data.

Another set of data is given in Stephenson in his summary of SAFEGUARD software (STEPHENSON, 1976). Again, with considerable variability one can see a roughly 3:1 ratio. The advantages of adequate time-margins also extend to verification and maintenance activities. With sufficient time for program execution, more attention can be given to clarity and conformance to standards, and software diagnostic and self-checking features can be employed.

The CERs developed in Sec. 2.2 are for code which is largely time-constrained. Thus if these cost relationships are to be used for non-time-constrained software, the cost figures can be divided by three (subject to the hazards noted above).

Structured Programming. One of the most widely discussed topics in the software literature is Structured Programming. Some authors suggest this is a wondrous new procedure; others are more reserved, saying it is nothing more than just being orderly.

A reasonable consensus is that it involves several specific procedures, including:

1. **Top-down programming:** This requires that software design and code be developed from the level of control logic down to the detailed logic level.
2. **Structured coding:** Each block of code is developed by adhering to a strict set of rules, and to a limited number of permissible sequences, such as:
 - **Simple sequences**, in which one operation follows another with no branching alternatives
 - **Selection sequences**, in which either of two operations may be used depending on a comparison or test
 - **Repetition sequences**, in which a set of instructions is repeated until some condition is fulfilled, at which time the loop is exited.

* ADPREP refers to the ADP Resource Estimating Procedure; the data were reported by Planning Research Corporation in Report R-152, August 1970. Other data sources noted in this paper include PARMIS (Planning and Resources Management Information System) at the Air Force Data Systems Design Center.

In short, these are straightforward sequences with single points of entry and exit (there are no GO TO statements). Another rule is that modules of code should be no longer than a single page.

3. Support Libraries: This is a centralized repository for the blocks of code throughout their development. The librarian is responsible for record-keeping and file maintenance, thus contributing to a more efficient division of labor (programmers can concentrate on programming).

There is little definitive evidence which precisely determines the cost impacts of structured programming. However, data from IBM, Safeguard, (NICHOLS, 1975), and other sources clearly indicate that there are two-to-five-fold cost savings for both development and maintenance.

2.4 Consideration of Interrelationships Among Life Cycle Phases

The preceding CERS have been developed--in large part--for individual phases of the software life cycle. These CERS--and others we have developed or have found in the literature--still exhibit considerable lack of precision. Thus, in our studies for the Air Force and NASA we began to explore additional factors which might explain the variation in observed costs.

From this point of departure we identified factors other than characteristics of each individual phase; namely, a number of significant interrelationships among phases of the software life cycle. These complicate the process of identifying cost determinants for each individual phase. To elaborate: our general approach to estimating the costs of a given activity is to focus on specific attributes of the activity which most strongly influence its cost. However, we find that a significant element in explaining, say, the cost of testing is the effort given to the earlier activity of software design. We believe--in effect--that there exists the type of relationship shown in Fig. 6. Over some range, this curve indicates if the effort given to design is reduced, there will be added effort required during the testing (as well as coding) phases because of errors and difficulties with the program. Conversely, additional time spent in design of the software will reduce subsequent effort required for testing (and for coding).

Similar arguments can be made about relationships between resources expended in coding or testing and the subsequent effect upon required maintenance resources after the software is installed. In these cases, man-months of coding or man-months of testing would be the abscissa, and man-months of error correction in maintenance would define the ordinate. We are currently exploring these relationships, the most important of which is hypothesized to be between design and the subsequent testing period. Our initial studies of these interrelationships have been inconclusive. We have not been able to compile sufficient data to prove (or disprove) the hypotheses noted above. This remains as a topic for further research.

Other continuing research activities include the following:

- Development of software sizing relationships in terms of basic mission descriptors (e.g., for surveillance systems, the number of lines of code as a function of number of targets, target speeds, range resolution, etc.)
- Development of specific hardware-software tradeoff relationships *
- Evaluation of the impact of Verification and Validation (V&V) upon acquisition and maintenance costs of software
- Development of cost control and cost reporting procedures for ongoing projects.

* As an example, we have addressed the cost impacts upon software development associated with hardware capacity-constraints. Increasing this capacity does, however, mean that the costs of hardware will be increased.

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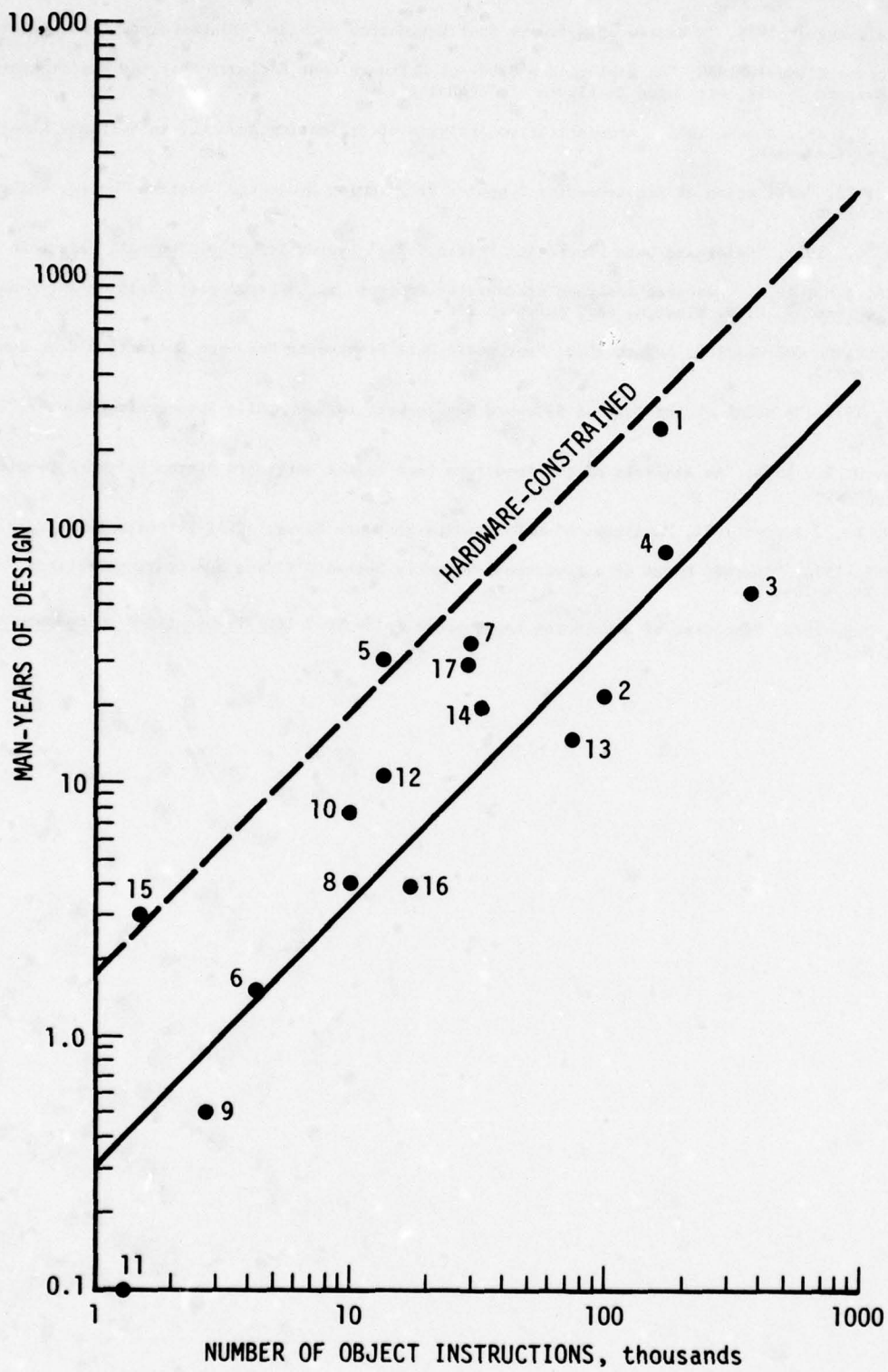


Figure 1. Design Relationship

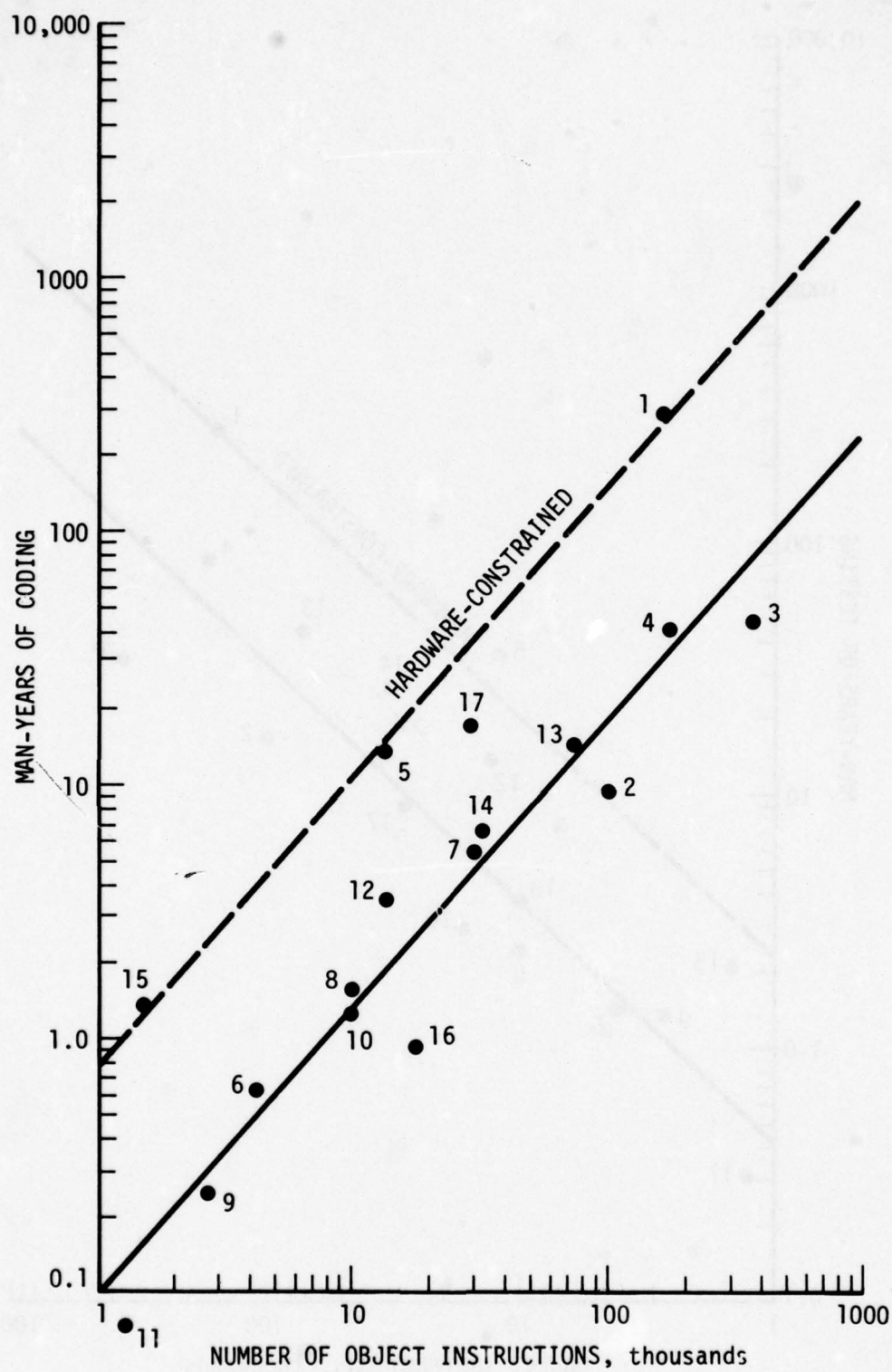


Figure 2. Coding Relationship

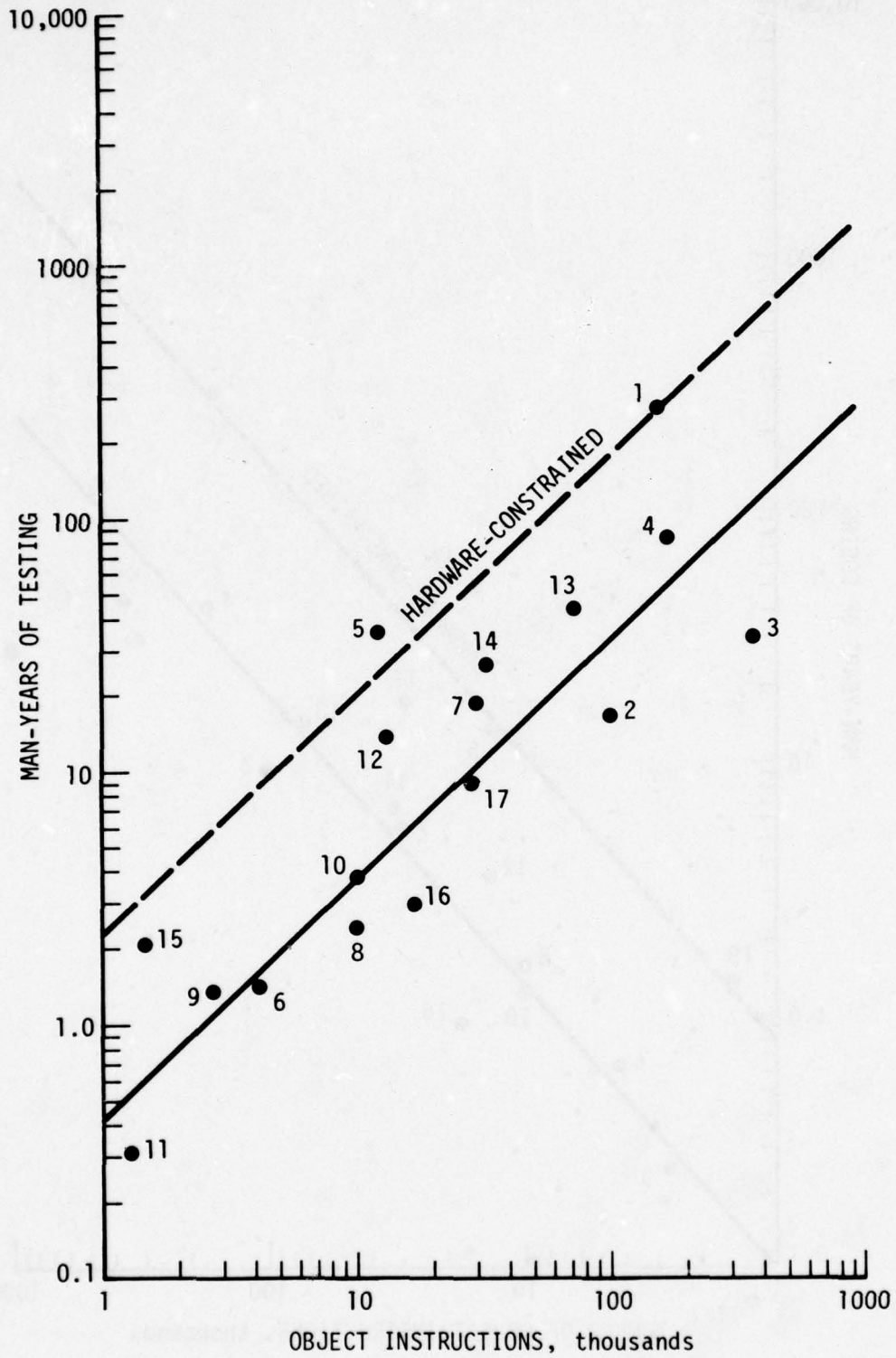


Figure 3. Testing Relationship

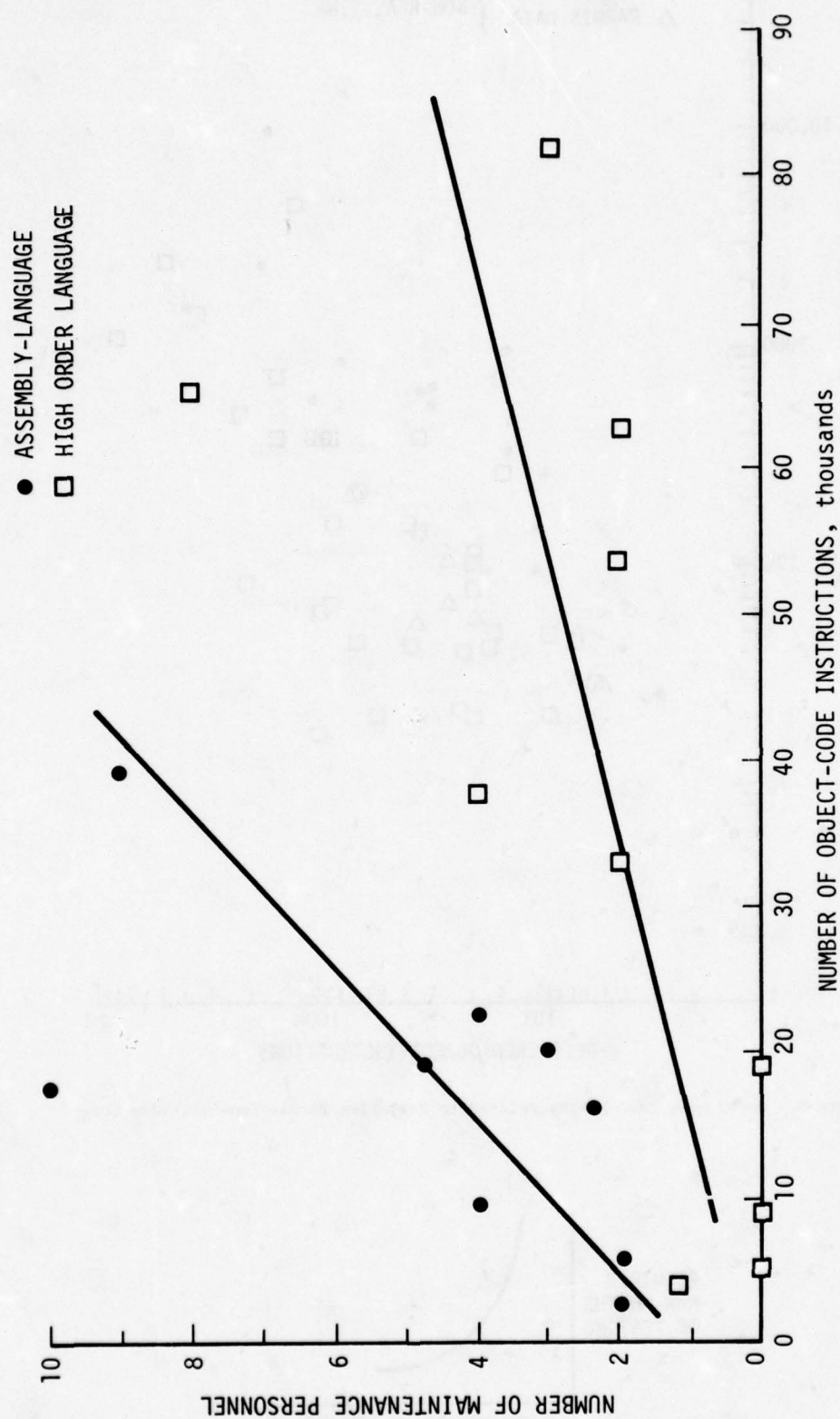


Figure 4. Maintenance Requirements for Machine-Language and High-Order-Language Programs

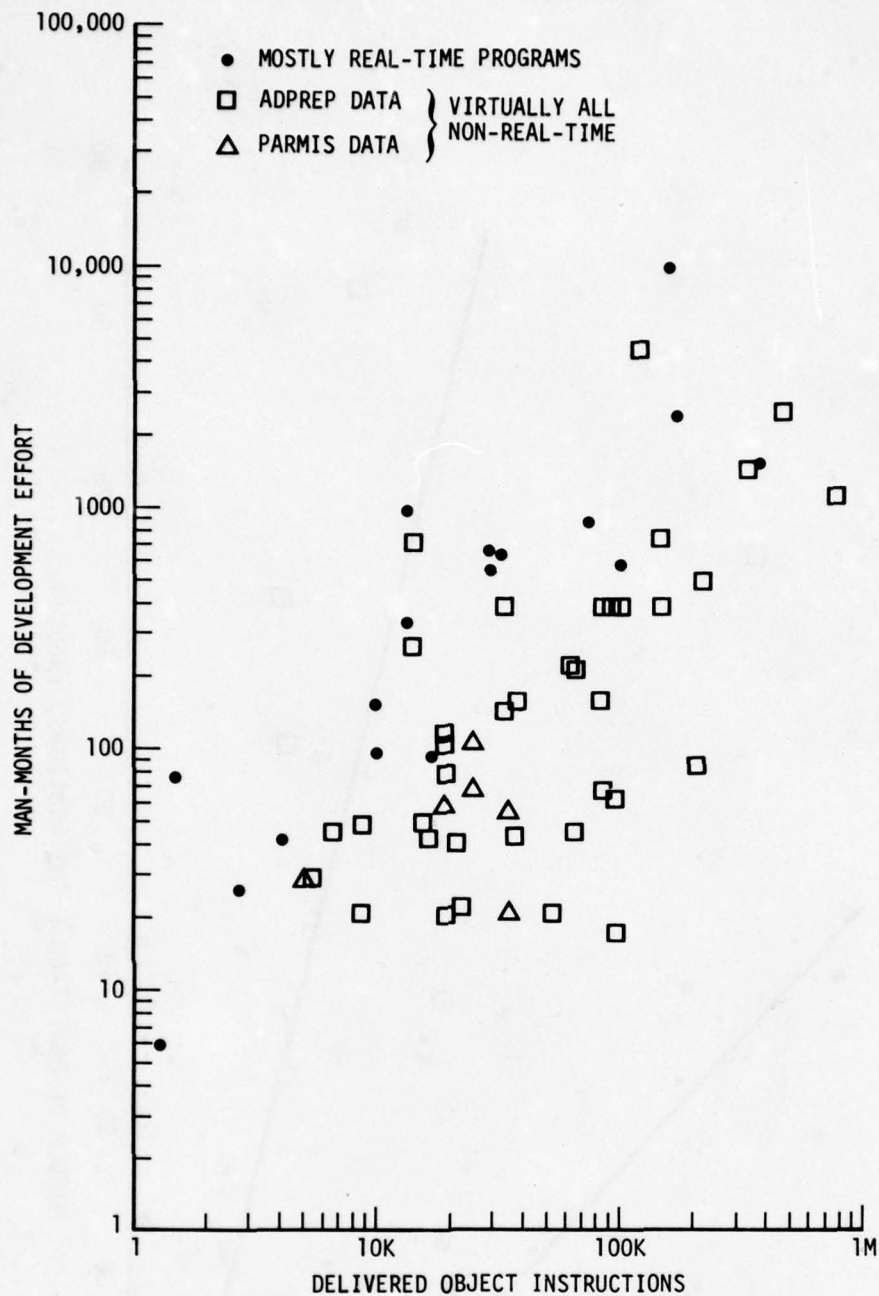


Figure 5. Development Man-Months Related to Real-Time Versus Non-Real-Time Code

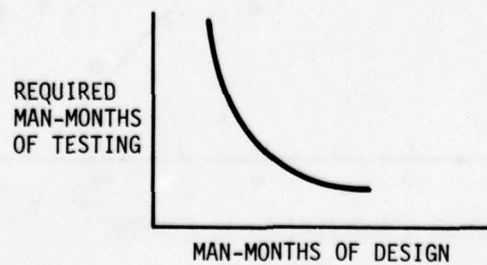


Figure 6. Design-Testing Tradeoffs

DISCUSSION

A.Hofmann

Your Figure 4 is easily misinterpreted; isn't it in favor of HOL, since HOL requires only one-third to one-quarter of maintenance effort? Actually a program written in HOL will be about 3 to 4 times the size after compilation of the one written in assembly language. Conclusion: Equal maintenance for HOL and assembler programs.

Author's Reply

The data I have suggests that the HOL assembly multiplier is generally less than 3 which still leaves an HOL advantage. I agree that the figure — as it stands — is misleading.

J.Shepherd

Have you been able to determine any cost relationships between the level of integrity required by software and the support software (assembler or HOL etc.) used?

Author's Reply

No; we have not attempted to identify this relationship; nor do I know of any work by others.

W.F.Neuberger

How do you estimate the number of instructions needed at the beginning of a program?

Author's Reply

I know of some work we have done to develop crude estimates of size for space navigation software, and others (I believe Mitre) have done for air defense systems software. In the latter, $size = f(\text{range of coverage, target resolution, data rates for target info...})$. Otherwise, not much has been done that I know of — in this field.

R.Nelson

- (1) How far back into the system design effort do you carry the software costing effort?
- (2) In particular, have you done or do you know of any studies relating the total software cost of a system to the amount of involvement of software people in the system engineering process?

Author's Reply

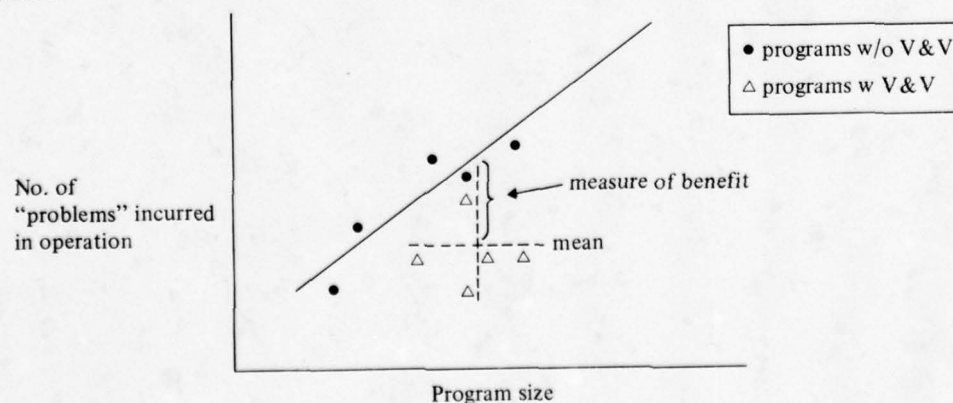
- (1) We have gone back into the analysis phase, but have found required resources are not functionally related to characteristics of the software. Rather, they are a function of the state of knowledge in the field which the software is serving (e.g. air defense, space navigation, etc.). Analysis is concerned with developing basic algorithms which will then be implemented in software (and/or hardware). The effort required to do this is not functionally related to the eventual software's characteristics.
- (2) I do not know of any studies which have related total software costs to early involvement in the engineering process.

Y.Brault

In critical functions on aircraft and spacecraft, verification and validation (V&V) is essential. What is the impact of V&V on the total cost of the software?

Author's Reply

I have some data on the cost of V&V plus some information on the benefits. These benefits have been "measured" as follows:



WORKING WITH TECHNOLOGY: DISTRIBUTED PROCESSING STANDARDS FOR THE EIGHTIES

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SUMMARY

A set of standards is described, the adoption of which should allow computer-based military equipments from a variety of sources to be developed in compatible fashion. Such standards are held to be necessary in the face of an increasing proliferation of small processor types. It is suggested that, without adoption of such standards, the current logistic and training problems of the Armed Forces will increase significantly as small computer-based equipments come into service.

1. INTRODUCTION

The severe disparity between the timescale surrounding computer evolution and that for the introduction of computer-based systems into military equipment is illustrated in Table 1 for 2 UK Naval developments. The situation is, however, significantly worse than shown in the table, since such equipments are currently expected to remain in service use for the hull-life of a ship (up to 20 years). Similar examples could be quoted for Army or Air Force projects. Effectively the Armed Services are being put in the position of having to maintain technologies well beyond the timeframe of their commercial viability. This brings the attendant problems of producing such technologies, and, when this is no longer possible, of finding good quality personnel who are prepared to provide post design expertise in such support.

With computer-based systems the situation to date, though difficult, has perhaps been manageable since architectures in use have been centralised and the range of computer types limited. This position is now changing rapidly with the advent of mini-computer and microprocessor-based weapons and distributed information systems. It is the authors' contention that, unless such equipments are as far as possible developed around a set of common standards, the already difficult task of maintaining such equipments in the future will grow significantly. It is proposed that this task can be eased by adoption of the following:

- (a) Military mini-computers and microprocessors that are code compatible with the machine code of a successful commercial machine.
- (b) A defined high-level language for program development.
- (c) Formalised support software for controlling real-time interactive application processes in an orderly fashion.
- (d) A common internal bus structure for store and peripheral interfacing.
- (e) A defined high-level serial interface for linking computers.
- (f) An equipment practice, specifying board size, connector type, cooling and power distribution philosophy.

None of these items is independent of the others and it is asserted that the adoption of a subset only would be undesirable. The rest of this paper is devoted to a more detailed description of the set of specific standards proposed as meeting this need for UK purposes.

2. HIGH-LEVEL LANGUAGE (CORAL) AND SUPPORT SOFTWARE CONSIDERATIONS

The availability of good support software is a vital ingredient in the success of any project which is procuring computer-based equipment. The term covers that standard "off-the-shelf" software which is common to all projects whether it is used during development only, or incorporated in the final operational system. In overview, it falls into 3 categories:

(a) Software to support the development of the "Application Software", normally known as the "Program Development System", including:

- (1) A multi-access operating-system with a good backing-store file handling system.
- (2) A good CORAL 66 compiler.
- (3) A procedural library.
- (4) A compatible interactive and batch source-text editor.
- (5) Source text composition and layout aids.
- (6) Debugging aids.
- (7) Specialised application testing and checkout aids.
- (b) Software to support the running of the Application software, therefore including:
 - (1) The "Real-Time Executive", MASCOT (see later).

(2) An Input-Output package to work with MASCOT.

(3) A procedural library.

(c) Test Software, which provides one (of several) mechanisms for checking out the computer hardware during commissioning, operational switch-on, fault identification or maintenance.

Two important observations may be made concerning the application support software (Category (b)). The first is that this software is the most difficult to standardise on for a particular computer, because it intimately affects the performance of the final system. Hence it must be an acceptable and agreeable standard to the users in theory and practice, and one which can be machine independent. We believe we have found this goal in MASCOT (see later).

The second observation is that the traditional "Program Development System" cannot support the majority of Real-Time applications, briefly because of run-time efficiency considerations. Thus Categories (a) and (b) have tended to be separate developments in the past. This is a pity because there is potentially a large amount of common software, and more seriously the testing of the application software is complicated by the transition between the 2 environments. The future here must be for the Program Development System to be built upon the Real-Time Executive, as is possible with MASCOT.

In the current state-of-the-art, the approach of basing a military computer on a viable commercial order code offers at least a ready made and maintainable Program Development System. This must include, for UK MOD purposes, support of the MOD preferred high level language, CORAL 66 (HMSO 1970). This language is block-structured, similar to ALGOL 60, but gives more efficient code generation. It is suitable for real-time applications by the provision of machine-code inserts as a means of flexibly interfacing to the external environment, rather than by the inclusion of particular "real-time" features which in any case would now be out of date. After 12 years of service CORAL 66 compilers are available for 55 computer models, of which 12 are fully MOD approved. Compilers for a further 28 models are under development, bringing coverage up to 24 manufacturers. "Standardising" on CORAL 66 has the advantage of avoiding the need to support other languages, even assemblers.

The notion of a "CORAL machine" was a major factor in the choice of the Ferranti Argus 700 computer range as the baseline for a military computer. The efficiency of a CORAL program at runtime depends not only having a compiler which produces efficient code, but also on having an architecture which is convenient for code generation. The Argus 700 architecture was designed from the start to be "CORAL conscious". Also with Argus 700 came the support software, covering the items listed (except Item (a)(6)), whose development is measured in units of man-centuries rather than man-years. Naturally, the support software is centred around CORAL and is largely written using it.

3. MASCOT - A FORMALISED REAL-TIME SUPPORT SOFTWARE METHODOLOGY

MASCOT (Modular Approach to Software Construction, Operation and Test) now possesses a UK Official Definition (MASCOT Suppliers Association 1978). MASCOT is a set of facilities for real-time programming, incorporating features concerned with systems development and construction. It is intended to influence and assist all stages in the life cycle of a software system, from initial design to maintenance and modification. MASCOT provides:

(a) A formalised methodology for expressing the software structure of a multi-programmed or real-time system which can be independent either of computer configuration or programming language.

(b) A disciplined approach for design, implementation and testing giving a concept of modularity for real-time systems and increased reliability by formal control over access to data.

(c) An interface to support implementation and testing methodologies both through a small kernel which can be implemented directly on a bare machine or on top of a host operating system and through software construction facilities.

(d) A strategy for documentation.

The total set of MASCOT facilities is shown in Figure 1 and the definitions of formal terms used in this diagram are given in the appendix to this paper. All MASCOT implementations are required to provide the synchronisation primitives (JOIN, WAIT, LEAVE, STIM), the suspension primitive (SUSPEND) and the termination primitive (ENDROOT). All bare machine implementations must provide an interrupt handler and all evolutionary implementations must include construction facilities, sub-system control facilities, a command language interpreter and a monitor facility. The additional facilities shown in Figure 1 are optional. It is intended that operational systems may be deemed 'FROZEN' and based around MASCOT implementations containing no construction facilities.

An example of one level of MASCOT documentation is an Activity Channel Pool (ACP) diagram as shown in Figure 2. Activities are processes which operate independently and asynchronously, and which co-operate by accessing Intercommunication Data Areas (IDAs), these latter being either channels supporting unidirectional data transmission or pools providing permanent or semi-permanent data areas. Channels may have a number of producer activities associated with the input interface and a number of consumer activities associated with the output interface. At each of these interfaces MASCOT's mutual exclusion facilities prevent access by more than one activity at a time.

4. MILITARY PROCESSOR DESIGN

An entirely novel design technique has been developed for the Military Argus Processor. This processor is based on an existing range of commercial machines, and uses 2901 4-bit slices, PROMs, and Programmed Logic Array chips. It is constructed on a pair of 6 in. x 9 in. cards (Double EUROCARDS), with an optional third store card.

The microcode for the new processor was generated and tested using a new HYBRID simulation technique, wherein the 4-bit slice chips which make up the heart of the design are attached to a HOST computer via standard TTL I/O parts. An area of core store is set aside within the HOST computer, and is thought of as "belonging" to the 4-bit slices. It is called PSEUDO CORE. Other than the 4-bit slices every entity which appears in the new computer (ie counters, gates, PROMs, PLAs etc) is simulated very precisely by software within the HOST. What amounts to a new high-level language has been developed for this purpose - the entire operation of the new processor can be described, down to the waveform level, within 600 lines of Teletype listing.

The microcode is debugged on the above configuration as an interactive teletype task. The entire design is checked by running the full diagnostic software package for the target computer within the PSEUDO CORE, ie before any hardware is constructed. Once the design has been finalised and fully checked, paper tapes are produced automatically from the simulation for directly programming the PROM and PLA devices which make up the bulk of the new design. In effect, the technique reduces the fabrication of the new processor to an interactive teletype task, since virtually all of the intricate wiring is now within these programmed devices. A further significant advantage is that the technique is self-documenting.

5. SERIAL SIGNALLING STANDARDS

The hardware concepts being advocated are illustrated in Figure 3, which shows computers constructed on cards of defined size, to a common internal interface standard and communicating with each other by defined serial links. Such concepts are by no means original; by and large a unique set is adopted by every computer manufacturer. However, only in a limited number of available serial links has there been any significant compatibility to date between the standards used by differing manufacturers. International standardisation authorities have made more progress in the furthering of these serial standards than in the other areas, probably for the pragmatic reason that it is here that users have most strongly encountered a requirement for interaction between different suppliers.

It is in this area also that one can most readily see legitimate reasons for divergence between Army, Navy and Air Force Systems, since there are significant variations in scale between cable links employed in aircraft or ships and on battlefields. There are a number of commercially neutral standards available which are suitable for inter-processor communication. Specifically these may be listed as:

- (a) NATO draft STANAG 4153 for shipborne use.
- (b) MIL STD 1553A for aircraft applications.
- (c) HDLC. Though a proposed commercial standard, HDLC is well suited to certain military applications, and its adoption now would offer a real prospect of military/commercial compatibility in the future.

In addition a requirement has been identified for fully broadcast working in future Naval systems, and a paper on a proposed solution given at this conference (Wells and Stainsby 1978).

6. INTERNAL INTERFACING STANDARD - MODBUS

When consideration was given to making a recommendation on an internal computer interfacing standard, the requirement for commercial neutrality left little alternative but to start afresh and define a new standard. There are in existence a number of apparently suitable interfaces (the best known in the PDP-11 Unibus) but all known at the time were proprietary. What has been defined is our implementation-independent interfacing standard, known as MODBUS. MODBUS specifies computer information transfer and control sequences on nominated lines, and it is envisaged as being applicable to a range of equipment practices. Inclusion of MODBUS in a specific equipment practice requires association of the nominated lines with specific edge-connector pins, the inclusion of necessary power supplies and shelf fault-reporting logic.

Devices using MODBUS for information transfer require access to 28 bussed lines eg:

- 18 Address/Data lines (18 bit Address width, 16 bit data transfers)
- 2 Byte Working lines (Byte Working, Byte Address)
- 3 Cycle Control lines (Cycle Begin, Cycle Response, Cycle Finish)
- 2 Access Control lines (Bus Grant, Bus Accept)
- 2 System Control lines (Reset, Cycle Abort)
- 1 Interrupt line

Devices which wish to initiate transfers of information each require an extra Bus Request line which is connected directly to a bus arbiter responsible for allocation and access control. A further starred (to the arbiter) line (Interbus Cycle Response) is required by devices performing linking operations to another bus. A typical system is shown in Figure 4.

The requirement that systems be constructed from a common set of compatible cards has had 2 significant design consequences:

(a) Cards in a MODBUS-based system will be position sensitive. This is normal engineering practice in the majority of electronic equipments, and in MODBUS it allows cards of like type to be substituted without prior setting-up or personalisation.

(b) System specific information is largely concentrated in back-plane wiring and the bus arbiter card.

This latter may contain interrupt routing information and, for optimum performance, specific arbitration algorithms.

To ease the problems of conformity with specified bus waveforms an LSI interface set is being developed. To an individual device designer using this set, the processes of seeking bus allocation and the management of information transfer along the bus will be invisible, and will be effected by a simple handshake.

MODBUS allocation is under the control of the bus arbiter unit. Though the exact algorithm for allocation of the bus by the arbiter can be system dependent, the basic design philosophy is such as to support efficiently cycle by cycle allocation between those units bidding for use. However, a master wishing to retain the bus for successive cycles without repetitive allocation requests may do so, unless its permission to use the bus is withdrawn by the arbiter. As far as possible 'look-ahead' allocation is employed ie allocation of the bus for the $(N + 1)$ the data cycle is progressed on the request and access control lines during the course of the N th data cycle.

The normal mode of information transfer across the bus is on a master-slave basis ie a device having requested and been granted use of the bus initiates a read, write or vector (address only) cycle. Information transfer during these cycles is regulated by the 3 cycle control lines, and all events are handshaken so that devices of differing speeds may be connected to the bus. Transfers which fail to elicit a response, or which violate bus rules, will be terminated by the arbiter using the cycle abort line. Such termination will not affect other devices using the bus, but good system practice requires that the fault condition be indicated. Though in general master devices must release the bus when their permission to use it is withdrawn by the arbiter, these performing indivisible cycles such as semaphore test-and-set operations may retain the bus for 2 successive cycles.

7. EQUIPMENT PRACTICE

A new equipment practice is required to provide a physical realisation of the modularity concepts which are central to our proposals. The term equipment practice is taken to include not only cabinets, racks and cards but also cooling, power supplies, all interconnections and the provision of maintenance and monitoring facilities. Some commercially neutral standards exist in equipment practices, as well as a vast range of individual manufacturer's approaches. The latter were rejected on the grounds that they were proprietary and as such it was felt that their adoption would create difficulties in bringing them into usage and in maintenance. Some deeper consideration was given to 3 commercially independent standards; namely ATR (Aircraft Transportable Racking), SEM (Standard Electronic Modules) and CAMAC (Computer Assisted Measurement and Control).

ATR is in widespread use but not sufficiently specified to be the complete equipment practice which we require.

SEM's were rejected on the grounds that the card size was felt to be inadequate for construction of such functional units as might be expected to result from reasonable partitioning in a modern computer system. Examples of the latter are processors, 32K store blocks and peripheral drivers.

CAMAC standards are widely used in the nucleonics and instrumentation fields. They form a possibly unique example of a voluntary group of users defining and maintaining standards which are willingly followed by a range of manufacturers. The practice itself is wide-ranging and well defined. However it was considered unsuitable on the grounds that it could not be re-engineered to military standards without major re-design. In addition the interfacing bus had a number of limitations when viewed against our general purpose data processing requirements.

Our chosen approach, as in the software case, was to adopt the commercial equipment practice which most nearly met our requirements. This is based on a 19 in. rack philosophy using Single (100 x 160 mm) and Double (233.4 x 160 mm) Eurocards, these standards (part of the DIN 41494 specification) now being very widely used in Europe. There are 2 connector areas on Double Eurocards (MODBUS being confined to the top connector only) and the associated 2-part connector (DIN 41612) is again fast becoming the commercial standard in Europe (Mil Version VG 95324). An outline Double Eurocard is shown in Figure 5.

Overall design philosophy is based on modularity at card carrier or shelf level, each of these Standard Equipment Units (SEU's) having an associated power supply, cooling unit and cable termination area. Thus one such unit with a suitable cover can form an independent small system, as could be incorporated in a console, or a group of 4 or 5 such units with an overall cover can form a conventional cabinet.

The modularity concepts also encompass a range of power supply units which may be in the form of:

- (a) Small pluggable units in the shelf.
- (b) Larger units mounted at the rear of the shelf behind the backplane wiring.
- (c) Large units which provide power to a whole cabinet.

Similar flexibility is required of the cooling system. To cater for a wide range of applications 3 main types will be developed:

(1) Forced-air circulation through the shelf venting into the compartment. This should form the cheapest system.

(2) Closed-circuit forced-air with heat-exchanger (air-to-water or air-to-air). This approach is most common in present systems.

(3) A chilled-water conduction-cooled system where it is required to remove more heat than possible under (1) or (2), or to operate in quiet conditions.

There is similar flexibility in shelf design to facilitate incorporation of modules etc in addition to single cards. All the associated parts (cards, shelves, power supply units, heat-exchanges and cabling) will be standardised. Thus any future system can be built up from standard parts with new items being developed as necessary.

8. THE WAY AHEAD

A set of standards meeting the requirements outlined in the introduction to this paper has been identified. Their expression in formal terms either existed (CORAL, MIL STD 1553A) was in hand (MASCOT) or has been deliberately progressed (MODBUS, Equipment Racking) in the work described here. Projects in the United Kingdom are now committed to developments based around these standards. An accurate assessment of the benefits of application of what is advocated can only be made in the future by contrasting through-life costings of those projects which have conformed, with broadly similar developments based around differing standards. The points proposed in the paper will have a finite life due to technological advance, and it is necessary that a near-continuous review be made of their relevance. Even today, it is appreciated that not all military computing tasks can conform to the proposals, electro-magnetic signal processing being an example of a specialist area where data-rates are significantly outside the scope of the foregoing. However, there exists a significant proportion of United Kingdom operational computing tasks that will benefit in development from adoption of these proposals, and these benefits should increase in operational use. If these assumptions are correct, then it appears reasonable to extrapolate to the statement that adoption of these, or a similar set, by NATO would bring benefit on a wider scale, not least being interoperability and compatibility of computer-based equipments. This seems a suitable subject for discussion in this forum.

9. REFERENCES

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Wells T D and Stainsby M G 1978. ADNET. An experimental information distribution system. Proceedings of AVP 36th Technical Meeting on Technology for Data Handling II.

<u>SHIP</u>	<u>TECHNOLOGY FREEZE</u>	<u>SHIP SET TO WORK</u>
HMS FIFE	1961	1968
HMS BRISTOL	1964	1973

TABLE 1(a) SHIPBUILDING TIMESCALES

<u>YEAR</u>	<u>TECHNOLOGY</u>
	Relays
1958	Valves
1961	Discrete logic
1964	RTL
	DTL
1967	TTL (SSI)
1970	TTL (MSI)
	ECL
1973	MOS
	TTL (LSI)
1976	Bit slice

TABLE 1(b) TECHNOLOGY EVOLUTION

APPENDIX

<u>NAME</u>	<u>DESCRIPTION</u>
Access Procedure	The class of procedure used to operate on a Channel or Pool data structure.
An Activity Channel Pool (ACP) diagram	A method for representing a MASCOT system diagrammatically.
Activity	A single thread in the multi processing system administered by the scheduler. The processing actions of an Activity are defined by its Root Procedure. The interactions of an Activity with other Activities are completely confined to a set of IDAs which are actual parameters of the Root Procedure.
Command Language Interpreter	The means whereby Kernel functions are made available to the user in an Evolutionary system.
Control Queue	The object in the Data Structure of an IDA which provides the focal point for software stimulation and mutual exclusion of one activity by another, by means of the Primitive operations WAIT and STIM, and JOIN and LEAVE.
Channel	The class of Intercommunication Data Area providing unidirectional data flow between Activities.
DELAY	The Timing Primitive which allows an Activity to delay further processing until a time, specified as a parameter in the call, has elapsed.
DELETE	The construction function that removes a sub-system.
ENDROOT	The Termination Primitive which enables an Activity to terminate itself correctly.
EXCLUDE	The Monitor function to remove a function, Activity or Control Queue from being Monitored.
FORM	The construction function used to build MASCOT Sub-systems from System Elements.
Function	A term used to describe the facilities provided in MASCOT for sub-system control and monitoring. A function is available for use by Activities via a procedural interface.
Handler	A routine which responds directly to an interrupt.
HALT	The sub-system control function which stops a sub-system but allows a subsequent restart. See also RESUME.
Intercommunication Data Area (IDA)	The means by which Activities interact. May be one of two types, Channel or Pool.
IPCON	The Monitor function to switch recording on or off.
JOIN	The Synchronisation Primitive which allows an Activity to gain exclusive access to a Control Queue.
Kernel	That part of a MASCOT system which provides the chosen scheduling, interrupt handling, sub-system control and monitoring facilities.
LEAVE	The Synchronisation Primitive which allows an Activity to release its hold on a Control Queue.
LOAD	The construction function used to create a System Element.
Monitor	A Kernel facility which provides a means of observing and recording the interactions between sub-systems and the kernel.
OPCON	The Monitor function to switch processing of recorded data on and off.
Pool	The Intercommunication Data Area providing storage of data which may be read or modified by a number of Activities.
Primitive	An indivisible operation within the Kernel.

<u>NAME</u>	<u>DESCRIPTION</u>
RECORD	The Data Recording Primitive which enables Activities to present data to the Monitor.
RESET	The Monitor function to return the Monitor to its initial state.
RESUME	The Sub-system Control function to continue the operation of a Sub-system from the point where it was stopped (see also HALT).
Root Procedure	The program which defines the operation of an Activity. The formal parameters of the Root Procedure define the number and type of the IDAs which the Activity will be able to access. It may also have value parameters.
SELECT	The monitor function which adds a function, Activity or Control Queue to the Monitored subset.
Slice	A period of execution of an Activity terminated by an interrupt or a return to the scheduler.
START	The Sub-system Control function which starts a Sub-system.
STIM	The Synchronisation Primitive operation by which an Activity can apply a software stimulus to a Control Queue.
Sub-system	The major unit of construction and control in a MASCOT system. It is created from System Elements by the FORM command.
SUSPEND	The Co-operative Scheduling Primitive by which an Activity can unconditionally return control to the scheduler.
System Elements	The Root Procedures, Channels and Pools which are used by the FORM command to construct Sub-systems.
TERMINATE	The Sub-system Control function which closes down all Activities within a Sub-system.
TIMENOW	The Timing Primitive which delivers the value of time used in delay measurement.
UNLOAD	The construction function used to remove a System Element.
WAIT	The Synchronisation Primitive operation which allows an Activity to wait for a software stimulus on a specified Control Queue.

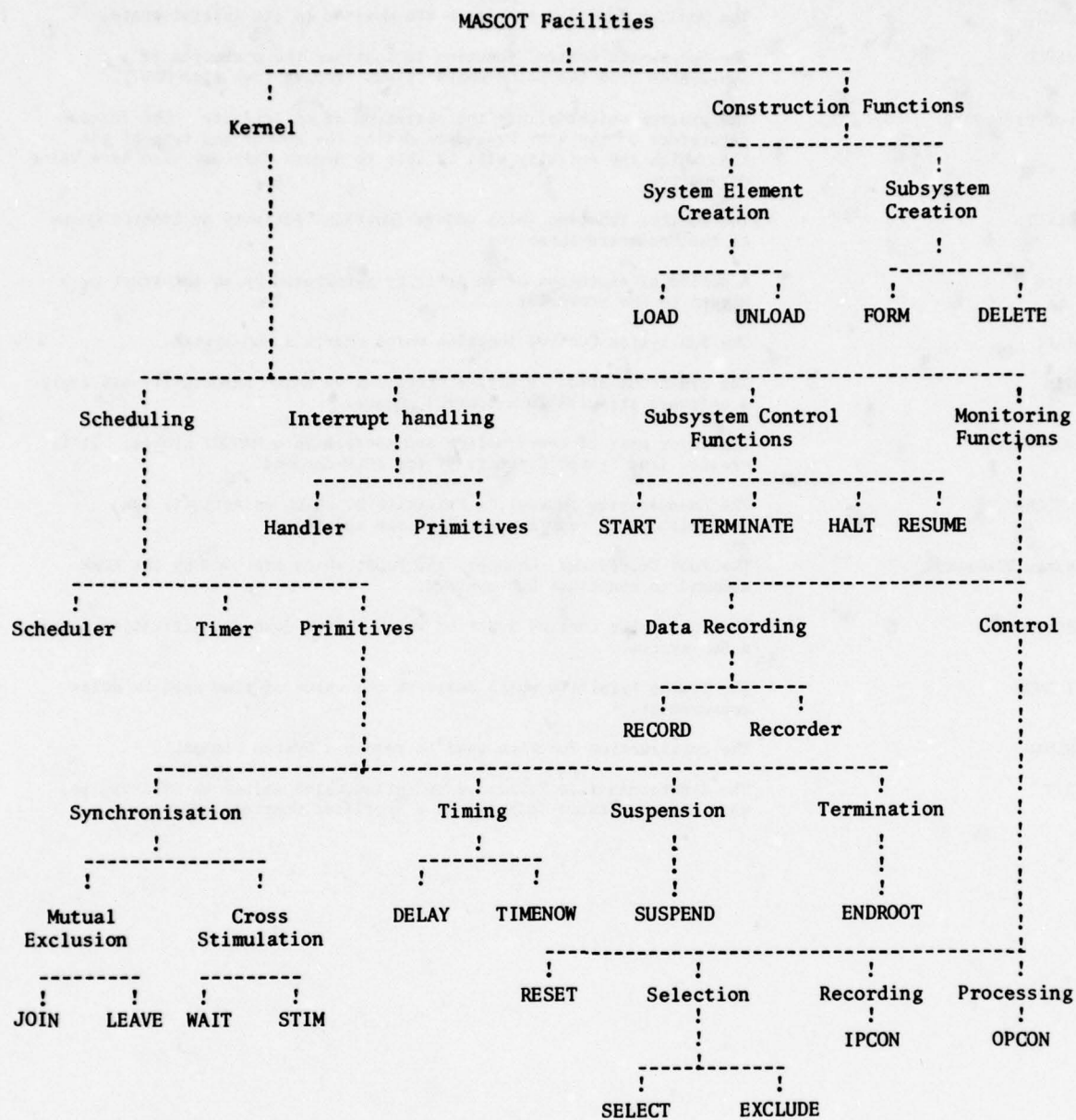


Fig.1 Summary of MASCOT facilities and functions

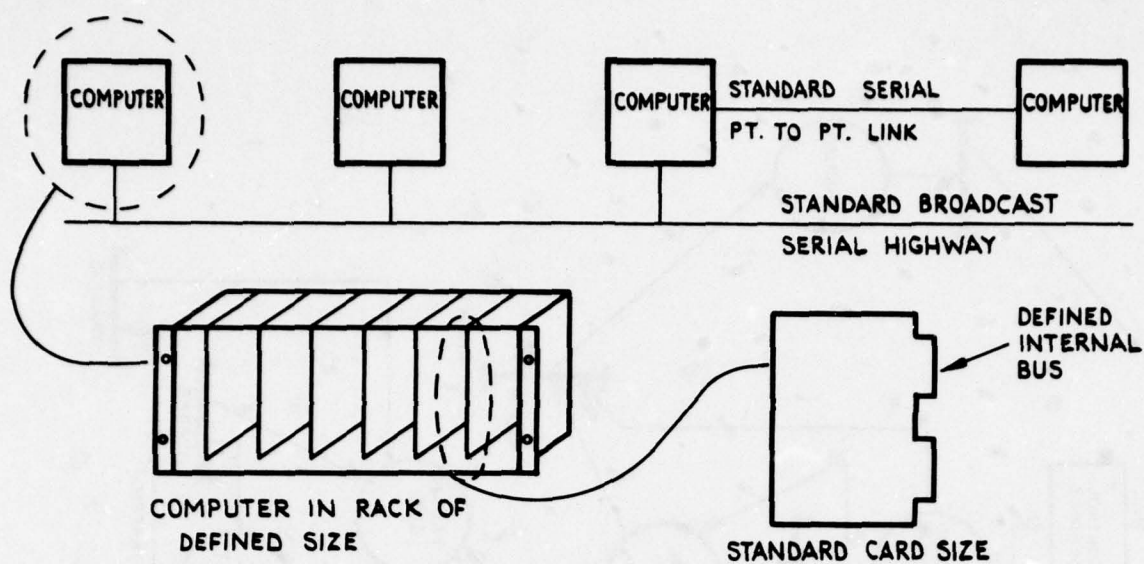


Fig.3 Concepts in hardware

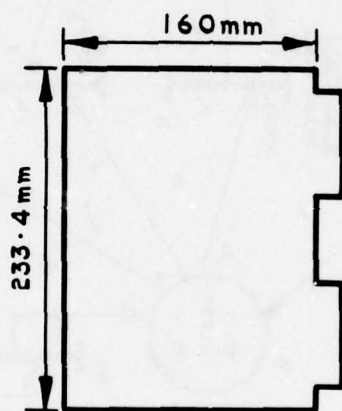


Fig.4 MOD bus system

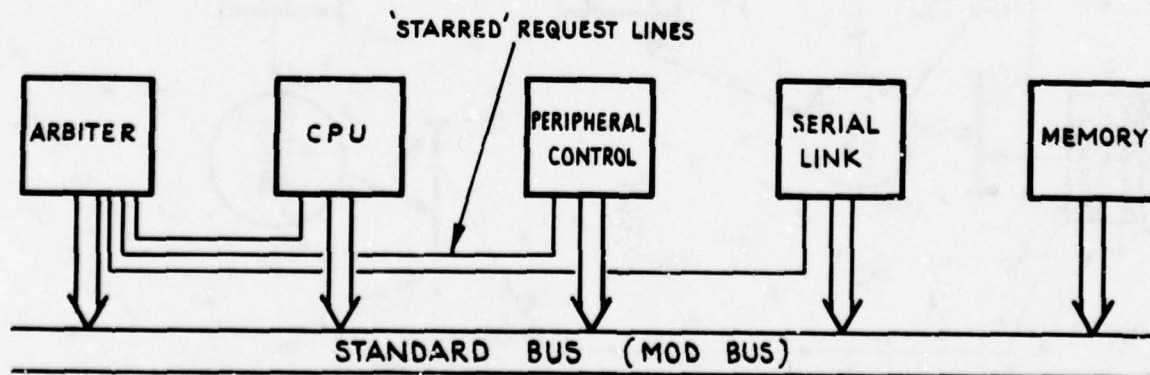


Fig.5 Double Eurocard

DISCUSSION

R.N. Oldfield

Although every manufacturer is extremely unhappy if he is forced to use someone else's standards and approach, it is a situation which has worked well in some areas and may become a more frequent occurrence (e.g. consideration of PDP-11 by DoD). Would not such an approach have significant advantages to the military in that it would increase the likelihood of continued support, rather than the use of a compromise standard in which no one manufacturer has a real commercial stake?

Authors' Reply

While this approach would have made life simpler for us in the short run, we believe this would not have been the way to achieve our aim of obtaining widespread support in industry. We also reserve the right to have multi-source supply possibilities by our current approach. This probably would not have been possible if we had chosen a manufacturer's own standard. If we are correct in our assessment of future requirements then the proposed proponents will have commercial possibilities.

J. Shepherd

Are we really going to get a standard system which will last 20 years or will it be overtaken by microprocessor architecture developments?

Authors' Reply

The intention in partitioning the system into major functional elements i.e., processors, 32K store, peripherals, etc. is that this will not be the case. Providing such units remain plug compatible and thus are capable of meeting the new communications requirements then we will achieve our aim of technological independence.

J. Shepherd

If MASCOT is as good as is claimed then why do the software houses not use it?

Authors' Reply

If it is true that software houses do not use MASCOT then it is due to the difference between the commercial requirements of software and the military requirements.

F.A. Østern

What kind of ruggedizing have you recommended for the double European cards to fulfil the environmental specifications, especially concerning vibration and shock?

Authors' Reply

The cards will meet the normal Naval specifications.

R.N. Oldfield

As a complete hardware and software package, the standards are unique and do not relate directly to a complete commercially available package. Other speakers have suggested that military efforts in this field will only succeed if they are taken up by the commercial field. Do you believe this will occur, and what are the implications of failure and of the commercial field to take up the standards with real enthusiasm?

Authors' Reply

We believe that where possible we have chosen commercially available packages. Where we have not done so e.g. interface, mod bus, MASCOT and LORAC 66 this was because no neutral commercial alternative was available.

PARNAS PARTITIONING

by

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ABSTRACT

From a logistics or maintenance viewpoint, NO changes should be permitted in the computer programs used to control operational weapon systems. From the viewpoint of effectiveness or performance, it is often NECESSARY to change the computers embedded in operational weapon systems, to react to a new threat, to counter a new enemy tactic or capability, or to support the needs of an associated new weapon system whose requirements for input data quality are more demanding. As a result, it is common for the software for embedded computers to be subjected to regular change, despite the associated logistic problems. Therefore, it is important to develop software design techniques which minimize the cost impacts of software changes.

At SINGER-Kearfott we addressed this issue for our guidance, navigation and communication products by turning to the modern structured software design methodologies which stress simplicity of form, readability of code, and hierarchical organization. While achieving some success, the cost of program changes was still unsatisfactorily high. We then turned to a technique originated by D. L. Parnas for partitioning computer programs to facilitate future changes.

This technique has been used on a number of Kearfott avionics systems (e.g., the AN/URQ-28 communications terminal for JTIDS) with significant success. There are numerous examples of small program changes accomplished at negligible cost and substantial program changes whose cost was very modest. This paper reviews the Parnas Partitioning technique and its application to avionics software by the use of pertinent examples. The most successful use of the technique for weapon systems requires participation by the software design engineer, the systems design engineer, the customer's project engineer, and the end user. The role of each of these participants is identified.

1. BACKGROUND

The use of digital control for new avionics systems is now essentially universal. One reason for this dominance is the substantial increase in flexibility which digital control systems provide in comparison to analog systems. The digital system designer often tries to maximize this flexibility by designing systems whose control functions are defined in memory devices which can either be easily replaced or whose contents are easily changed. Since this design approach makes it easy to replace one control program by another, it would appear that the flexibility of these systems is assured. Changes in the control system are usually reduced to being "simply software changes". (Incidentally, in this paper we shall use the term software to refer to any program, even if it is stored as "firmware" in ROM memory.)

However, we soon find that it is not so easy to develop the software design change required to implement a particular control system change, especially for large, complex software systems. This problem is often referred to as the Software Maintenance Problem and it is now well known that much more money is spent by the DOD on software maintenance than on software development. Have we then deluded ourselves on the flexibility of digital systems? Have we merely traded a hardware change problem for a software change problem?

Of course this is not true. Even with the substantial expenditures required to maintain control system software, the implementation of design changes of similar scope in analog systems would be dramatically more expensive. In fact the changes themselves would often not be undertaken due to their prohibitive expense. So we agree that the flexibility of digital systems is not illusory, however, this flexibility is severely limited by the Software Maintenance Problem. In fact, our intuition tells us that we should be able to develop technical and managerial approaches to dramatically reduce the Software Maintenance Problem thus improving the flexibility of the systems which they control. This paper is devoted to the identification of one such technique which has been successfully used by the Kearfott Division of The Singer Company to develop flexible avionics software. Since the technique is as much managerial as it is technical, it promises to have value for all types of software. In fact it should prove useful in the design of more general systems as well.

Before pressing on with the exposition of this approach, we should consider the question: Is this search for design flexibility NECESSARY, or are we merely succumbing to the engineer's tendency to continuously refine his design, beyond the point where any useful gain is obtained in system performance? There is no universal answer to this question. Certainly in some cases the persistent changing in system software is excessive. Some changes do not make a system truly "better", rather they merely make them "different". However, the new flexibility provided by digital systems has prompted the design of systems which depend in a crucial manner on the ability to make

rapid implementation changes. For example, digitally controlled ECM systems are now developed which depend for their success on current knowledge of an adversary's radiation habits. When he changes his radiation habits (say by the introduction of a new weapon), we MUST change the control of the ECM system accordingly. Consequently, anything which limits our ability to change this ECM system rapidly and efficiently, serves as a limit on the system's ability to respond to a new threat or strategy. It is therefore important for us to find solutions to the Software Maintenance Problem.

2. INTRODUCTION

The desirability of designing modular programs appears to be one of the axioms of computer software engineering. It is neither proven nor questioned. Programmers have been trying to build modular programs for almost two decades. But what is meant by a modular program and what is a module? Let's consider the following candidate definition: A program is modular if it is decomposed into a number of small manageable modules. While we could probably get near universal agreement on the validity of this statement, it does nothing to clarify the meaning of the phrase "manageable module". A search of the literature will reveal that many guidelines have been proposed for use in defining a manageable module. Several of these are listed below:

- o Modules must be independent of each other.
- o A module implements an indivisible function.
- o A module should have only one entrance and exit.
- o A module does not affect parameters other than its formal arguments.
- o The function of a module is unaffected by:
 - °the source of its input
 - °the destination of its output
 - °the past history of the module.
- o Modules must be small, i.e.,
 - less than 100 statements, or
 - less than 10 decision statements, or
 - one page of source code, or
 - one page of flowchart, etc.
- o Modules must be separately compiled.
- o Modules should have uniform work content
 - e.g., each requires one manmonth to develop.
- o Modules must be separately testable.

It would certainly be very useful if we could show that one or more of these definitions of a manageable module were sufficient to guarantee the flexibility of the resulting program product. Unfortunately, experience has shown that many programs, which are highly modular by one or more of the above guidelines, exhibit unsatisfactory performance characteristics. In particular, these definitions of modularity do NOT appear to be the answer to assuring flexibility in program design. This is not to say that the above precepts do not have beneficial effects on program design but that there are many examples of good, modular programs (by the above criteria) that are still difficult and expensive to change. What are we missing? Could the unsatisfactory performance of our "modular" programs be traced to a weakness in our definition of modularity?

3. THE PARNAS APPROACH

According to a paper by D. L. Parnas in 1972 (1), we are indeed missing a central ingredient in our definition of modularity. He illustrates this weakness through the medium of a very simple example, a program to generate a KWIC (Key Word in Context) index from a set of input word strings representing titles of books or papers (for example). A KWIC index is a listing of all rotations of the words in the title. As an illustration of this process, consider the titles of the papers presented at the previous session at this Conference on Tactical Data Processing Hardware (see Figure 1). Each paper title is provided to the KWIC Index program as a character string input. The program must generate all possible rotations of each title (see Figure 2). Then the program must print all the rotated titles in alphabetic order (see Figure 3).

Let us now design a modular program to perform this function. We can begin by partitioning the program into a set of modules consistent with ALL the modularity criteria presented in the previous section. One obvious candidate for such a partitioning results in modules for each of the following functions:

- o Input of word strings representing titles

- o Rotation (circular shift) of word strings
- o Alphabetizing the rotated word strings
- o Output of KWIC index
- o Master control

With a module to perform each of these functions, we have a partitioning of the problem that satisfies all the above guidelines for good module design. Figures 4 and 5 depict the control flow of this modular program and the invocation hierarchy respectively.

The key question now is whether this modularization or partitioning of the problem will result in an easily maintainable program. That is, can we expect to be able to easily modify this program to accommodate future changes in requirements? To answer this question, we shall consider the impact on the program of certain expected design changes. But first we must develop some additional design detail about each of these modules.

The Input Module is responsible for reading the input lines of text from the input medium. The input is a character string with blanks to delimit the words. These lines are then placed in common memory for use by other modules, using the following design details:

- o Characters are packed, 4 to a memory word.
- o An index is formed to show starting address of each line.
- o A special character (*) is inserted to designate end of line.

The Rotation Module scans each line placed in memory by the Input Module. It creates an index to the first word in each rotated version of a line. This table of indices requires much less memory than if each rotated line were replicated in memory.

The Alphabetizing Module generates a table of indices to the first word in each rotated line such that the entries in the table are in alphabetical order. This is achieved by scanning the table of indices provided by the Rotation Module in conjunction with the representation of the line stored in memory. A new table of indices is then constructed whose entries are in alphabetical order.

The Output Module prints each rotated line in alphabetical order. This is achieved by processing each index in the table provided by the Alphabetizing Module in their order of occurrence. The index is used as a pointer to fetch the desired line from common memory for printing in the desired format.

The Master Control Module is little more than a traffic cop. It performs the following functions:

- o Controls sequencing among other modules.
- o Handles error returns from modules.
- o Generates error messages.
- o Handles space allocation.

Now we are ready to determine whether this modularization is easily adaptable to change in design decisions. If so, it would indicate an easily maintainable product. If not, we would be forced to conclude that our partitioning of the problem did not achieve its primary purpose and would have to search for a superior modularization. Toward that end, let's consider the following candidates changes in the system design:

- 1) Revise the format of the input word strings. For example, the designation for end of line might be changed.
- 2) Change the output format. For example, instead of printing the alphabetized lead word of a rotated line left-adjusted on the page, we might print the alphabetized lead word in the center of the page, with the other words in the line printed in their original order to the left and right of the lead word.
- 3) To increase the portability of the system between computers of different word size, we might change from packing four (4) characters per memory word to packing one (1) character per memory word. We thereby increase portability at the expense of memory efficiency.
- 4) To expand the system to handle very large input files, we might want to store the word strings on disc rather than in main memory.

What impact do these proposed changes have on our program?

The first two changes are easily handled, since they each impact a single module, with NO impact on other modules in the system. Change #1 can be entirely handled in the Input Module and Change #2 can be entirely handled in the Output Module. So with respect to these changes, our modularization is very effective and the program appears to be very easy to maintain.

However, the results are not so good for Changes #3 and #4. Each of them affect FOUR program modules! Only one module (Master Control) is unaffected by these changes. The root of the problem is the fact that all four modules directly access the lines stored in main memory. So a change in the format used to store these lines must be accommodated by all four modules. Therefore, if these changes are likely to occur, this modularization will not result in a program which is easy to maintain, i.e., to change.

Can we amend our design to better accommodate Change #3 and #4? Ideally, we would like the effect of each change to be localized to a single module. Parnas' suggestion is to make an explicit list of design assumptions or characteristics which are likely to change in future versions of the system. Then when you partition the problem to form your program modules, select a partitioning which succeeds in hiding each design assumption in as small a portion of the program as possible. The design assumption might be hidden in a single statement (if possible), or in a single module or in a minimum number of modules. Then, if future changes are of the type indicated in your list of changeable design assumptions, you can be assured that their impact is highly localized. You can confidently expect that a localized design change can be much more easily implemented than if its impact were to spread over many modules. A corollary of this approach is the realization that if you do not know the nature of probable future changes to your system, you are likely to be unsuccessful in selecting a problem partitioning which will localize the impact of these changes.

To illustrate the power of this approach, let's return to the KWIC Index Program, realizing that one of our changeable design assumptions is the specific format and organization of the line storage activity within the computer (since both Change #3 and #4 are of this type). The next step is obvious. Construct a Line Storage Module which handles all access to lines in memory. It would naturally hide all assumptions on line format from the other four modules, which would have to call it. The basic functions of the Line Storage Module are listed below:

- o Provides total interface with lines of text stored in memory.
- o Interfaces with other modules on a character basis.
- o Uses index to reference characters in text.
- o Performs several line-access functions.

Figure 6 shows the revised invocation hierarchy chart. Note that the control flowchart does not change, which indicates that the control flow will not usually be a clear indicator of the modularization which facilitates future change.

As a result of adding the Line Storage Module to our partitioning of the KWIC Index problem, we appear to have created a design which is easily adapted to handle the type of changes envisioned. However, it is important to realize that this flexibility has been achieved at the cost of program efficiency. The need to use the Line Storage Module for all line access will probably have a detrimental effect on the size and speed of the overall program. But this increased cost may be worthwhile if in fact the anticipated changes are eventually implemented. If the anticipated changes are not eventually implemented, we will have decreased the efficiency of the program to no purpose. It follows, then, that the list of design assumptions used to select the partitioning of the problem must be carefully selected. It is not sufficient that one can conceive of changing a design assumption, the likelihood of that change must be high for it to be included in what we have come to refer to as the Hiding Assumption List. If the entries in this list are capriciously selected, we can expect inefficiency in the resulting program product. In short, the decision to add the Line Storage Module to the KWIC Index program must be considered a poor design decision if changes in line format are NOT likely to occur.

In summary, then, the Parnas approach requires that you build a list of changeable design assumptions whose impact you wish to hide from as much of the program as possible. We've come to refer to this as the Hiding Assumption List. The program is then designed to localize the impact of each change represented on the list.

4. PARNAS PARTITIONING IN AVIONICS SOFTWARE

At Singer-Kearfott we develop software for computers embedded in our GN&C systems. Our primary motivation in developing these programs is to avoid the need for future change (pursued via careful specification and exhaustive checkout). This is especially true for our general purpose products such as the AN/ASN-128 Doppler Navigation System and our Standard Inertial Navigation System. Since this Utopia is very difficult to achieve, our next line of defense is to minimize the impact of future changes. Since many of our navigation systems have the control program implemented in Read Only Memory (ROM), this provides another motivation to localize the impact of design changes to a few ROM devices, thus protecting our investment in the remainder of the ROM memory.

Prior to our decision to use the explicit Hiding Assumption List proposed by Parnas, we carefully modularized our avionic programs by the prior criteria for proper modularization. We also employed many of the precepts of structured programming and top-down design. Although there were beneficial effects on program development cost, readability of code, etc., we were still plagued by the high cost and schedule impact of program changes. Upon reading the paper by Parnas (1), it became clear that we could NEVER expect to develop a program modularization to successfully handle a change we were unaware of. That is, the suggestion seemed eminently reasonable that successful partitioning of the problem could only be assured if you developed an EXPLICIT list of expected design changes and used their localization as a criteria for selecting the problem partitioning. This technique, which we came to refer to as Parnas Partitioning, we then began to use for our avionics software development. At first it was used on small systems with substantial success. Then we began to use it even for our larger systems, with a continuing record of success. In this paper we shall illustrate the use of the method on our Joint Tactical Information Distribution System (JTIDS).

To set the stage for our discussion, a few words are in order on the nature of the JTIDS concept. It is a form of digital radio which enables cooperating users equipped with JTIDS terminals to communicate with each other and to perform precision local navigation. It is based on using digitized electromagnetic radiation for two purposes, viz.:

- 1) Transmit secure information among cooperating users based on a complicated modulation and encoding of the waveform.
- 2) Compute range between any two cooperating users by measuring the time required for an interrogating pulse to be returned.

The resulting system provides an unprecedented communication and navigation capability within a single system.

Singer-Kearfott has been engaged in the development of the JTIDS concepts from their inception. Most recently, Kearfott developed the AN/URQ-28 JTIDS Terminal for Class 2 applications, i.e., tactical aircraft. This terminal provides:

- o Secure communication within community using digital TDMA techniques.
- o Distance measurement using RF ranging to cooperative members.
- o Accurate relative navigation via Kalman mixing of all navigation data.
- o Integral TACAN navigation system, sharing TDMA RF receiver.

The TDMA (Time Division Multiple Access) facility is based on dividing time into 7.8 millisecond intervals (slots) and synchronizing all users to this slot structure. Each slot is assigned for a particular purpose, using a common slot assignment algorithm throughout the community. Control of the Class 2 terminal is handled by an embedded computer, one of our SKC3120 family of computers. The embedded computer employs a mixture of RAM, ROM, and EROM as its main memory. The functions implemented in the control software are outlined in the accompanying top-level function chart (Figure 7). Since this collection of communication and navigation functions had never before been implemented as a single program and since the scope of the message communication function was greater than all the predecessor systems, it was obviously likely that significant changes would be required during the lifetime of this system. Our challenge was to implement the software in a manner which would facilitate later change.

The Parnas Partitioning concept seemed ideally suited for use in this application. Moreover, our contract called for the implementation of a "modular program" so we were quick to seize on the Assumption Hiding List as not only a design tool but also to serve as a means of communications with our customer on the modularity decisions as they were being made. Since the concept was new to project personnel outside the Computer Software Department, the first version of the Hiding Assumption List was prepared by Software Engineers, taking as broad a systems view as possible. The list was then supplied to Systems Analysts to solicit their participation in refining its content. Following this, the list was successively provided to Systems Engineers, Technical Management, and Program Management within Kearfott and then to our customer representatives. This broad participation was sought since the list can contain assumptions from all levels, including: system requirements, system design, and software design. At each level, useful comments were received and participation was enthusiastic. Since the design assumptions were usually top level concepts, they could be expressed in language understandable by everyone in this refinement sequence. We now believe that this is one of the major advantages of the Parnas Partitioning approach. It does not require knowledge of Computer Science in general or even knowledge of the design details of the program in question, for someone to participate in constructing the Hiding Assumption List. All that is required is the ability to predict which features of the system design are likely to change in the future. This of course requires knowledge of the system design and its ultimate application, but not of software design. For operational systems, we even suggest that the list of participants in constructing the Hiding Assumption List be expanded to include the end user of the system. In this fashion he can supply his concept of system flexibility DIRECTLY to the software designer in a manner that is both directly usable in software design and easily

reviewed by all other involved parties. In short, we feel that one major advantage of the Hiding Assumption List is its ability to be used for communication by ALL personnel involved in establishing system requirements or system design, since it is written in plain English.

As a result of this extensive refinement process, a large Hiding Assumption List was generated for the software to be designed for the JTIDS Class 2 Terminal. To illustrate the typical content of such a list, a portion of the JTIDS Hiding Assumption List is presented below:

- o The format, content, and priority of JTIDS messages.
- o The characteristics of external dead reckoning navigation system (cycle rate, scaling, format, accuracy, etc.).
- o The criteria for message screening and routing.
- o The number of slot sequences used during coarse synchronization.
- o The criteria for generation of range interrogation.
- o Algorithm for selecting member for ranging.
- o Format of TACAN output: Range & Bearing.
- o Number of dynamic states in relative navigation filter.
- o Relative navigation observation logic: number processed, selection logic, validity criteria, etc.
- o Format of message at I/O ports.

These assumptions and the many others contained in the full list were then used as a primary criteria for partitioning the software design. In many cases, the desired flexibility could be achieved by selecting a design alternative with no attendant degradation in software efficiency. The desire to hide a design assumption in a single module occasionally proved very difficult. In these cases a determination had to be made on the proper compromise between program efficiency on the one hand and program flexibility on the other.

The software design which resulted from this use of the Assumption Hiding List has already shown signs of being very flexible and adaptable. During initial integration of this software with the new terminal hardware, confusion arose as to the specific signals required for Input/Output operations (as often happens in new systems). In this case, however, the logic for each interface had been implemented in a macro which was invoked at several points in the program. The signal confusion was readily resolved (i.e., within a couple of hours) by changing a couple of lines of code in the macro definition. A reassembly then produced a corrected program ready for further integration testing. Much later in the development cycle, the customer developed an improved standard for message formats. This change is now being incorporated in the delivered program. Thanks to the first item in the Hiding Assumption List, this change is confined to the few modules which were permitted to be dependent upon the message catalog format. If the Hiding Assumption List were not used as an explicit criteria for partitioning the problem into modules, it is easy to envision the need for a much more revolutionary change to the program with almost all modules affected. The use of Parnas Partitioning thus cut down the effect of this change to very manageable proportions.

However, it should also be stated that these early attempts to use Parnas Partitioning were not 100% successful. Although the good examples mentioned above are reasonably typical of our experience on all projects, there were also some cases where the requested change was not localized and the effort required for its implementation was not trivial. There appeared to be two primary causes for these problems:

- 1) The type of change was NOT listed in the Hiding Assumption List, so the design activity did not attempt to localize its impact.
- 2) The actual implementation had wandered from the intent of the original partitioning decision due to laxity in enforcement of the isolation decisions.

While it is always more pleasant to achieve 100% success, there must be significant solace in the realization that the two problems listed above are not weaknesses in the Parnas Partitioning approach, but in the way it was conducted. Therefore it should be possible to eliminate them in future systems by aggressive management action.

5. OTHER ASPECTS OF PARNAS PARTITIONING

The apparent simplicity of the Parnas Partitioning concept belies its profound effect on the design of a complex software system. Like many good ideas, its beauty is in its simplicity. It is this simplicity which assures its success as a medium for communication between the diverse disciplines involved in developing the modern avionic system. Since the items in the Hiding Assumption List used for Parnas Partitioning are expressed directly in English, contributions to the list may be obtained from: Software Engineers, System Analysts, System Engineers, Technical Management, Program Management, customer representative, and even the end user of the system. In short, anyone who can initiate a change in the system can contribute to the Hiding Assumption List. By canvassing all these contributors, we would hope that the resulting List would be complete, that is, no changes with significant probability of occurrence are omitted. As we saw in the previous section, the omission of a probable change from the List can make the modularity decision ineffective, since the resulting system design is vulnerable to the omitted change. So we see that the List can be too short. However, the list can also be too long. If it is expanded to include all changes which the contributors can think of, the buildup of inefficiency in the resulting program may become intolerable.

So we are faced with the dilemma of a Hiding Assumption List that is either too long or too short. How do we resolve this dilemma in practice? We suggest the following steps be followed to provide sufficient modulation to the basic partitioning concept to assure its practicality:

- 1) Develop an initial Hiding Assumption List that is as large as possible---while it never helps to add impossible changes to the List, any other changes are acceptable.
- 2) Order the initial List according to the probability of occurrence of the change---there is no need to have a quantitative measure of this probability, the ability to rank all changes according to their relative probability of occurrence is sufficient.
- 3) Determine what design action is required to minimize the impact of each change. Categorize the impact of each design change on the efficiency of the program (is its impact on efficiency High, Low, or None?).
- 4) Immediately accept the design actions which have no impact on efficiency. They represent design alternatives which provide insurance against the corresponding change at no cost.
- 5) Review the remaining entries in the ordered Hiding Assumption List, starting with the most probable entries. Determine the acceptability of each design action based on the likelihood of the change and the magnitude of the efficiency impact. In some cases it will be desirable to seek a more moderate design action which provides some measure of protection against change but with an acceptable impact on efficiency.
- 6) When the inefficiency in the program has built to the margin of tolerability, reject all design actions which lie lower on the ordered List.

This technique is an attempt to buy the maximum insurance against program change with the minimum cost (i.e., impact on efficiency).

If the Hiding Assumption List is such a good communication medium, can it play a role in formally contracting for an avionics system? While we have no current experience on such a formal level, it certainly appears that the Hiding Assumption List could be a very useful contractual vehicle. In fact, whenever a contracting agency wants to impose a requirement for software flexibility or modularity, it cannot expect effective compliance without stipulating the types of changes to which the program will be subjected. The Hiding Assumption List provides this information. Even if the Hiding Assumption List is not used as a formal contractual item, it is important to realize that the flexibility of a system design is critically dependent upon the user's communication to the designer of his desires for future change in the system. There appears to be no such thing as flexibility in the abstract. Flexibility means adaptability to change, and the changes should be stipulated. Incidentally, we would expect the use of the Parnas Partitioning concept and its associated Hiding Assumption List to be easily generalized from software systems to ANY systems for which flexibility is a design goal. These might include GN&C systems, ECM systems, fire control systems, or even aircraft, ships and spacecraft.

However, there is one common objection to the apparent simplicity of the Parnas Partitioning approach, which takes the form of the following observation: "If I could specify all future changes in a system---I could develop the final system in the first place. But I don't know all future changes, therefore, the Hiding List must be incomplete". What this objection fails to take into account is the fact that the details of the design change do not have to be known in order to construct a Hiding Assumption List. It is only necessary to identify those design assumptions which are likely to change. It is NOT necessary to specify the new design assumption for the purposes of partitioning the system design to localize the impact of a change in design assumption. Parnas Partitioning can therefore be effectively used for systems where your only knowledge of a possible change is the fact that your current design assumption will be revised.

6. CONCLUSION

Our limited experience has revealed the high utility of the Parnas Partitioning approach to the design of flexible avionics computer software. We expect that the technique is readily adaptable to all types of software design as well as to the design of any complex system where flexibility is a design goal. In fact, imposing a design goal of modularity or flexibility WITHOUT providing the associated Hiding Assumption List would appear to be inherently ineffective. General purpose flexibility is likely to prove to be an ill-defined goal.

However, it should not be concluded that the Parnas Partitioning approach will obsolete other modularity criteria. It continues to be desirable to have small, manageable modules and the various design criteria for their construction (see the Introduction for a list of candidates) should be used in conjunction with Parnas Partitioning for best results.

For future research, we would hope to see the development of a metric by which the flexibility of a design could be measured. This development would permit the designer to measure the effectiveness of two design alternatives for hiding a particular design assumption and thus permit an objective selection of the best design approach. At present, our implementations of the Parnas Partitioning technique are based on a subjective selection among such alternatives.

In closing I would like to borrow a quote from the book (2) by Tom DeMarco on Structured Analysis and System Specification which underlines the importance of designing to facilitate change.

"The idea of freezing the specification
is a sublime fiction.

Changes will not go away
and they cannot be ignored."

---so, we'd better learn to plan for them.

7. REFERENCES

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AVIONICS INFORMATION PROCESSING ARCHITECTURES
 TACTICAL AUTOMATED MESSAGE PROCESSING SYSTEMS
 ALPHANUMERIC DATA TACTICAL COMMUNICATIONS TERMINAL
 NEW GENERATION OF TACAN EQUIPMENTS

Figure 1: Titles of Sessions

AVIONICS INFORMATION PROCESSING ARCHITECTURES *
 INFORMATION PROCESSING ARCHITECTURES * AVIONICS
 PROCESSING ARCHITECTURES * AVIONICS INFORMATION
 ARCHITECTURES * AVIONICS INFORMATION PROCESSING

TACTICAL AUTOMATED MESSAGE PROCESSING SYSTEMS *
 AUTOMATED MESSAGE PROCESSING SYSTEMS * TACTICAL
 MESSAGE PROCESSING SYSTEMS * TACTICAL AUTOMATED
 PROCESSING SYSTEMS * TACTICAL AUTOMATED MESSAGE
 SYSTEMS * TACTICAL AUTOMATED MESSAGE PROCESSING

ALPHANUMERIC DATA TACTICAL COMMUNICATIONS TERMINAL *
 DATA TACTICAL COMMUNICATIONS TERMINAL * ALPHANUMERIC
 TACTICAL COMMUNICATIONS TERMINAL * ALPHANUMERIC DATA
 COMMUNICATIONS TERMINAL * ALPHANUMERIC DATA TACTICAL
 TERMINAL * ALPHANUMERIC DATA TACTICAL COMMUNICATIONS

NEW GENERATION OF TACAN EQUIPMENTS *
 GENERATION OF TACAN EQUIPMENTS * NEW
 TACAN EQUIPMENTS * NEW GENERATION OF
 EQUIPMENTS * NEW GENERATION OF TACAN

Figure 2: All Rotations of Titles

ALPHANUMERIC DATA TACTICAL COMMUNICATION TERMINAL *
 ARCHITECTURES * AVIONICS INFORMATION PROCESSING
 AUTOMATED MESSAGE PROCESSING SYSTEMS * TACTICAL
 AVIONICS INFORMATION PROCESSING ARCHITECTURES *
 COMMUNICATIONS TERMINAL * ALPHANUMERIC DATA TACTICAL
 DATA TACTICAL COMMUNICATIONS TERMINAL * ALPHANUMERIC
 EQUIPMENTS * NEW GENERATION OF TACAN
 GENERATION OF TACAN EQUIPMENTS * NEW
 INFORMATION PROCESSING ARCHITECTURES * AVIONICS
 MESSAGE PROCESSING SYSTEMS * TACTICAL AUTOMATED
 NEW GENERATION OF TACAN EQUIPMENTS *
 PROCESSING ARCHITECTURES * AVIONICS INFORMATION
 PROCESSING SYSTEMS * TACTICAL AUTOMATED MESSAGE
 SYSTEMS * TACTICAL AUTOMATED MESSAGE PROCESSING
 TACAN EQUIPMENTS * NEW GENERATION OF
 TACTICAL AUTOMATED MESSAGE PROCESSING SYSTEMS *
 TACTICAL COMMUNICATIONS TERMINAL * ALPHANUMERIC DATA
 TERMINAL * ALPHANUMERIC DATA TACTICAL COMMUNICATIONS

Figure 3: KWIC Index

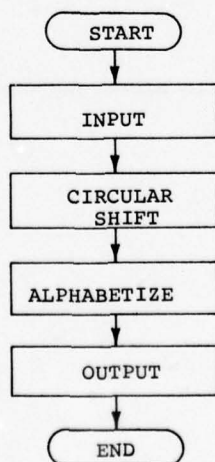


Figure 4: Control Flow

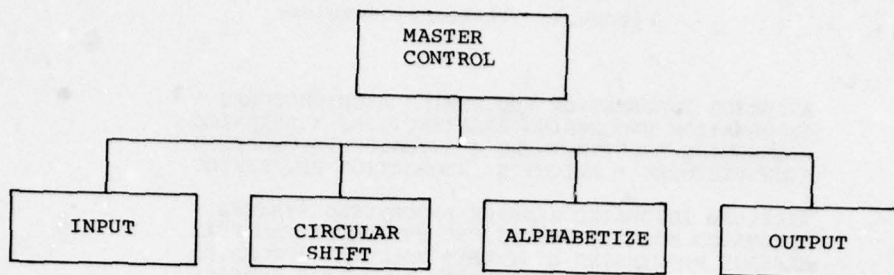


Figure 5: Module Hierarchy Chart

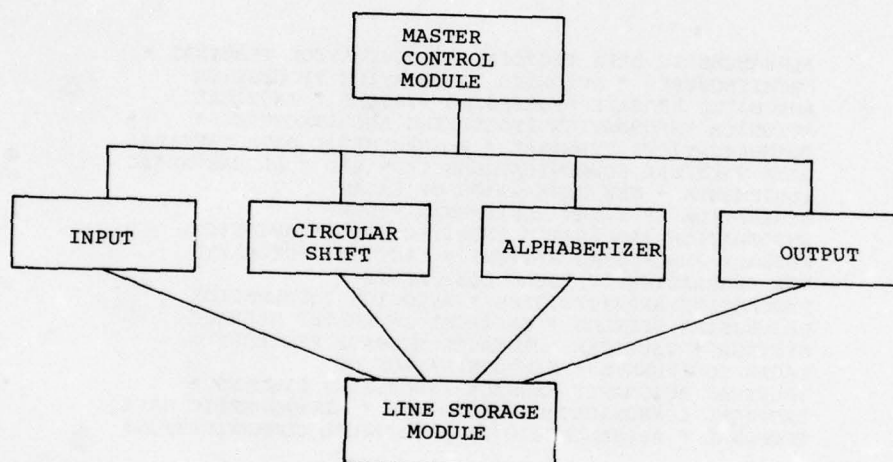


Figure 6: Module Hierarchy Chart (Revised)

DISCUSSION

Question

Was the use of the Parnas approach uniformly successful in your experience? We have not been successful in applying it thus far.

Author's Reply

While we have not always been successful in designing an implementation which successfully hides a particular design assumption (for example the size of the Kalman Filter State Vector shown on the JTIDS hiding assumption list), we have always been successful in designing simple implementations to hide almost all of the desired design assumptions. These design decisions represent a clear improvement in the flexibility of the resulting program product so we conclude that the Parnas Partitioning concept has always been successful for us. You should not be discouraged by the discovery of a particular design assumption (such as Kalman Filter size) whose affect on the program is so pervasive that it defies local isolation. Your efforts should be concentrated on those design assumptions which are amenable to isolation. In our experience, most design assumptions fall into this class although there is often substantial opportunity for design innovation in selecting the particular implementation which most successfully facilitates the future program change.

A. Clearwaters

What language was the terminal system programmed in?

Author's Reply

The terminal system was programmed entirely in Assembler Language for the SKC3120 computer. Extensive use was made of the floating point arithmetic capability which was built into the computer and of the Macro capability provided by the Assembler program.

A. Clearwaters

What impact would the availability of more modern language concepts, such as structures of the form found in C or ALGOL 68, have on your concepts?

Author's Reply

The availability of more modern language concepts would have had no effect on our program decomposition decisions using Parnas Partitioning since these considerations are language independent. That is, the selection of the possible program changes with high probability of occurrence is *not language dependent*, nor is the decomposition of the program into modules which hide these design assumptions. Thus, the availability of a high-order language compiler, such as the SKC FORTRAN compiler which was recently developed for our SKC 3121 computer, would not affect our modularization although it might have some effect on some of our implementation decisions. For example, since a source code substitution (Macro) capability was not provided by the SKC FORTRAN compiler, we would either have to use sub-routines in place of macros, where that implementation selection was made, or employ a FORTRAN preprocessor such as RATFOR in conjunction with the SKC FORTRAN compiler to provide Macro capability. In either case, the modularity decisions for our program system would be preserved.

R. Nelson

The examples of hiding assumptions you presented seem to apply at a high level of program decomposition. Did you use the list at lower levels of decomposition and did you circulate the detailed assumptions as widely as those at a higher level?

Author's Reply

While the examples of hiding assumptions shown here are all on a high level, they were selected for presentation based on their understandability by a mixed audience such as this. In fact the wording of some of them has been modified to increase clarity. Our full hiding assumption list did include many low-level design assumptions as well. The full assumption hiding list was circulated to all Kearfott participants in the review of the JTIDS program design. While the full list was available to our customers as well, our presentations of program status usually were based on the major (high-level) design decisions and they were encouraged to participate on this level.

HIGH ORDER LANGUAGE STANDARDIZATION

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ABSTRACT

Standardization is approaching us from virtually every aspect of the computer world, but nowhere is standardization of hardware and software receiving more emphasis than within the Department of Defense (DOD). This paper explores one aspect of DOD standardization, namely, High Order Programming Languages (HOLs). Serious attempts at HOL standardization have been with the general computing community for close to two decades and with the military for over ten years. HOL standardization has remained one of the most visible, yet relatively unsuccessful and controversial efforts in DOD. The reasons for this situation and the rationale for the new DOD approaches to HOL standardization are discussed from the historical, technical, and political standpoints. Special emphasis is given to the Air Force standard HOLs known as JOVIAL (J3) and JOVIAL (J73).

HISTORY

The first FORTRAN compiler was issued at the beginning of 1957, and by the end of 1963, there were at least 43 compilers carrying the name "FORTRAN" in their designation. Sammet (Samml) provides evidence that not only did these implementations differ between manufacturers, "... but within the same manufacturer ..." (i.e. the same features were handled differently even on IBM machines). There should have been an immediate lesson there, but for some reason(s) it didn't take. Many people argued it was still easier to transfer FORTRAN programs from one computer to another than it was to rewrite assembly language programs and were satisfied with that situation.

During the early 1960's there appeared on the scene what has been called the first multipurpose programming language, namely JOVIAL. The language was originally intended for Air Force Command and Control Systems, but languages called "JOVIAL" have been used by all three services and industry for the development of Tactical, Avionics, Electronic Warfare, data management, and even airline reservation systems.

There are numerous "dialects" of JOVIAL, which have been given designations such as J0, J1, J2, J3, J4, J5.1, J5.2, J3B-0, J3B-1, J3B-2, J6 (now called SPL), J73, J70, and JS. Each of these dialects will differ mildly or radically from another taken at random. Even within the same dialect, distinct implementations implement features differently.

Directly, or indirectly, the DOD has funded each and every implementation of JOVIAL or JOVIAL-like language. For the IBM 360/370 computer, the following compilers have been implemented:

Three J3 compilers (each totally different from the others)

Two J5 compilers (fairly similar)

Four SPL (J6) compilers (upwardly compatible subsets)

Three J3B compilers (upwardly compatible subsets)

In addition, a J73 compiler is planned in the near future for the computer series.

Forgetting for the moment all the dialects and differences in implementation, DOD has obtained systems written in many HOLs. A representative list would include AED, ALGOL, APL, BASIC, CMS-2, COBOL, FORTRAN, JOVIAL, LISP, NELIAC, PASCAL, PL-1, SIMSCRIPT, SPL, SPL-1, and TACPOL.

The above examples were given to illustrate the two important characteristics DOD is now attributing to the word "standardization" as it is applied to HOLs:

- (1) There will be a *single* official definition (specification) of the HOL which will be adhered to.
- (2) There will be only a few HOLs and "dialects" of HOLs which are approved for DOD use.

Characteristic (1) means that "like", "similar to", and "is a subset of" programming language X is not acceptable. In laymen's terms, only oranges will be called "oranges" (i.e. tangerines, tangelo's or grapefruits will be considered apples).

when compared to oranges). Characteristic (2) means that there is a low upper bound on the number of languages that DOD will use and provide support for (i.e. compiler developments, training aids, support tools, etc.).

These ideas are certainly not new, and if one takes the time to review references (WATT1 and SHAW1) it is apparent that studies performed in the early 1960's screamed for "... a standard programming language for Command and Control" (WATT1).

Why then didn't HOL standardization of some form come about much earlier? Actually, "standardization" efforts for HOLs did begin in the early 1960's and by 1966, there existed United States of America Standards Institute (USASI) standards for FORTRAN and Basic FORTRAN. (USASI was renamed the American National Standards Institute (ANSI) in 1969.) By 1967, the Air Force issued AFM 100-24, "Standard Computer Programming Language for Air Force Command and Control Systems" which established JOVIAL (J3) as the standard for Command and Control applications and provided a "standard" definition of the HOL. Similar efforts were underway for COBOL and ALGOL as well.

So, what happened? That question is analogous to, "Why wasn't former President Nixon's voluntary 50 mph speed limit adopted by the public in the Fall of 1973? The answer is it was (a) voluntary and (b) had no teeth. Historically, this is the case with HOL standards which stopped after the production of an official specification of some sort.

Each of us who did not heed the voluntary 50 mph speed limit knows why, but why the resistance to HOL standardization? The following is a representative list of actual reasons why a particular standard HOL was not adopted or its official specification not adhered to:

- (1) "Language XYZ is going to be available some day soon and it should meet my needs better." Usually if XYZ even came about it became necessary to wait for ABC which would be available next year.
- (2) "Allowing me to add/delete/modify these features will allow me to optimize the compiler/take advantage of my hardware/save money."
- (3) "Standardization will stagnate the state of the art."
- (4) "Professor What's-His-Name said that language is aesthetically displeasing/doesn't have string concatenation/cramps his style."
- (5) "Not invented here."
- (6) "The compiler doesn't produce efficient object code."
- (7) "I can't afford a compiler."
- (8) "The compiler will take too long to develop."
- (9) "We didn't use that language the last time and the system worked."
- (10) "They told me it was language QBX when I bought/leased the compiler, and its too late to change now."
- (11) "What standard?"
- (12) "That's not what I thought the specification said."
- (13) "That language is no good for 'real-time'."

It is the opinion of many, including those who have drafted the most recent DOD and Air Force policies on HOL Standardization and those who advocate the development of the DOD Common HOL commonly referred to as DOD-1 that a strong standardization program won't have much effect on the first five of the above reasons, but could even eliminate most of the others.

STANDARDIZATION TOOLS

The definition of what is "strong" standardization of HOLs differs among organizations and individuals implementing such standardization, but almost without exception, it is now generally agreed that a specification is not enough. Over the past decade, various concepts, elements of policy, and even tangible tools have arisen which support various approaches to HOL standardization. The tools will now be described independently of any particular philosophy of the day.

(1) The Formal Specification: A problem that has plagued both official and unofficial HOL specifications from the very beginning is their ambiguity of interpretation. The earlier FORTRAN specifications consisted only of English text and examples. English is of course ambiguous, and when the paper by John Backus (BACK1) used a formal notation, now known as Backus Normal Form (BNF), to handle the syntax of ALGOL, it was a welcome blessing. However, while BNF-like descriptions are still popular and can even be checked for ambiguity and completeness by feeding them into automated tools referred to as meta-compilers or compiler writing tools, BNF does not describe the semantic and the "context-sensitive" parts of a HOL description. In the late 1960's and early 1970's, vehicles appeared for providing the complete (syntactic and semantic) descriptions of a programming language in a formal, mathematically rigorous manner. While these formal specifications have proved difficult to read by laymen, they have been successfully used to locate incomplete and otherwise ambiguous parts of HOL specifications which use some natural language such as English as

part of the description mechanism. Two of the more successful formal specification tools are known as Hoare's Axiomatic Method (HOAR1) and the Semantics Oriented Language (SEMANOL) (BELZ1). The SEMANOL development was Air Force sponsored and SEMANOL has been used to specify JOVIAL (J3), JOVIAL (J73), BASIC, and CMS-2.

(2) The Compiler Validator: A tool which has proved valuable to virtually every serious HOL standardization effort is the set of test programs which test for a compiler's adherence to the HOL specification. An official specification coupled with a compiler validator (the test programs) provide an effective, yet austere mechanism for enforcing standardization. Of course, some kind of legislation is necessary to require that a compiler pass all the validation tests before it is accepted. At present, there are two problems with state-of-the-art compiler validators, namely their inability to trap language extensions, and their lack of rigor in testing those complex black boxes called compilers.

(3) The Compiler Generator, sometimes called the Root Compiler: The HOL is absolutely useless without a compiler, and the long time necessary to develop compilers, the high cost, and the generally unstable condition of a new compiler were and can still be good reasons for not using a HOL. Some compilers have taken 25 man years of experienced talent and as long as three years to develop to a stable state (STEE1).

Sammet states that "... a very bad compiler may render the language useless". Experience has taught that the bulk of the users do not really distinguish between the compiler and the language itself, and judge the language solely on the compiler they are familiar with. Thus, the availability of high quality compilers is absolutely essential for language standardization to be accepted.

Up to 70 percent or more of a compiler can be totally machine independent, and even some early compiler writers tried to capitalize on this characteristic to cut down on development cost and time and not "reinvent the wheel" with each new compiler implementation. The basic approach is to logically separate the machine dependent and machine independent compiler parts to the greatest degree possible and then code the compiler in its own language (such as JOVIAL), a special compiler writing language (such as SYMPL), or a popular programming language (such as FORTRAN). This approach is often coupled with the use of a tool known as a meta-compiler or compiler-compiler which takes a BNF-like (or similar) description of a programming language and automatically produces the lexical and syntactic analysis parts of a compiler. The bulk of the work required to get the compiler to run on a different computer and/or get it to produce code for a different computer will be concerned with modifying the code generation portion of the compiler and (the computer dependent part) to produce code for the new computer. Dunbar (DUNB1) and Gries (GRIE1) provide good tutorials on these techniques.

Almost every new compiler built today employs some variation of the above because of the following benefits:

- (a) The lower cost and shorter development time for subsequent implementations is attractive.
- (b) The overall quality of the compiler will be preserved or increase throughout subsequent implementations.
- (c) Maintenance costs can be spread over several implementations.
- (d) The language processed will be consistent across all implementations.
- (e) The same training and programming aids can be used across different implementations.

The above benefits have led some individuals and organizations to the conclusion that the true path to HOL standardization is to require the use of a single compiler generator or root compiler for all implementations of the language.

(4) The Code Auditor: This tool was invented for use with compilers that may have extensions beyond or deviations from the standard. This program is often implemented as the pre-pass to a compiler and flags the use of features which are to be avoided. Variations on this theme are now used to enforce coding standards such as "structured programming".

(5) The Statistics Collector: This tool provides data on how the language's features are being used, misused, and/or unused. If it is planned to modify or update the language to conform to modern requirements or programming style, to tune portions of the compiler to be optimal for various applications, or to identify troublesome features, this tool can be extremely valuable and provide concrete data where opinion and general intuition was the primary motivation for decisions in the past. For example, the tool described in (WHIT1) has provided the ANSI BASIC committee with data which has been used to reject the idea of a "continuation" line (it showed the average BASIC statement to be about 20 characters) and settle arguments on the final value of the loop control variable.

(6) Language Support Environment: Such environments consist of several tools which support the use of the language by making various tasks associated with the development and maintenance of software more efficient and less risky. Such tools are generally very sensitive to any changes in the syntax and semantics of the language they support. This directly promotes the use of the HOL as well as standardization. The high cost of some of these tools also forces standardization on a very few HOLs, especially when people become dependent on the tools. Examples of such tools are Path-Testers (GANN1), Programming Support Libraries (TINA1), Formal Verification Systems (ELSP1), and Code Auditors (SMIT1) like those discussed previously.

OFFICIAL ACTION

Regardless of the quality of the tools available, standardization cannot be effective without some official sanction. Within DOD, this sanction has come with Department of Defense Directive 5000.29 (DODD1) and Department of Defense Instruction 5000.31 (DODI1).

Department of Defense Directive 5000.29 requires that only DOD approved HOLs be used to develop Defense system software, and that each approved HOL be assigned to a control agent. The control agent "... will be responsible for such activities as validating compliance of compiler implementations with the standard language specifications, gathering data as to the use of the language ..." and "... assuring language stability".

Department of Defense Instruction 5000.31 lists the DOD approved HOLs cited above along with their official specifications. The approved HOLs are FORTRAN, COBOL, SPL-1, CMS-2, TACPOL, JOVIAL (J3) and JOVIAL (J73). Control responsibilities are assigned for each HOL: CMS-2 and SPL-1 are to be controlled by the Navy; TACPOL by the Army, the two versions of JOVIAL by the Air Force; and FORTRAN and COBOL by the DOD Comptroller. The final key element of the Instruction is that the control agents will be allowed to extend and improve their designated HOLs once per year to meet changing requirements.

Air Force Regulation 300-10 (AIFR1) specifies that the Air Force Systems Command (AFSC) will be the control agent for the two versions of JOVIAL, and limits the Air Force to use only the approved HOLs FORTRAN, COBOL, JOVIAL (J3) and JOVIAL (J73). AFSC has responded to its JOVIAL responsibilities by setting up an initial control mechanism (RADCI), with the principal players being the Computer Resources Planning section of AFSC (AFSC/XRF), the Rome Air Development Center (RADC), a Focal Point for each DOD user organization, all DOD and industry JOVIAL users, and last but not least, HQ USAF.

The Computer Resources Planning section is the Designated Control Agent for JOVIAL. (Hereafter in this paper, "JOVIAL" will mean both approved dialects of JOVIAL unless otherwise stated.) The Designated Control Agent is the only real power in that he has the final word on any action concerning both the policy with regard to JOVIAL and the actual language itself. He assures that DOD and Air Force policy is followed, seeks exceptions to higher authorities' policies when necessary, and has the final decision on language extensions. When the developer/user of a weapon's system is an element of AFSC, the DCA and the other players have further duties which will not be discussed here.

Due to the complex nature of HOLs such as JOVIAL, the Designated Control Agent has delegated the technical "legwork", associated with control of the language and support of the users, to the JOVIAL Language Control Agent. For an approximate two year period, RADC will be the Language Control Agent, with this responsibility being transferred elsewhere after that period.

The Language Control Agent has the actual responsibility for assuring the stability and configuration of JOVIAL. In that capacity he provides recommendations to the Designated Control Agent on proposed language extensions and deviations and/or their use, and maintains a service center for technical language expertise. That service center is now known as the Language Control Facility and has the following responsibilities:

- (1) Maintenance of the approved baseline JOVIAL Standard.
- (2) Maintenance of a directory of standard compilers.
- (3) Testing compilers for adherence to the approved standard specification.
- (4) Providing technical advice to users on the language and compiler development and acquisition.
- (5) Providing all necessary administrative support to an official JOVIAL Users Group (discussed below).

The Focal Point is selected by the product division, laboratory, or participating major command and approved by the Designated Control Agent. His primary function is to assure communication between the organization he represents and the other language and policy control mechanisms. He is the interface to the user community, provides advice on HOL standardization issues, and reviews and coordinates requests (from those he represents) for use of non-approved languages and proposed changes to the language standards.

The Language Control Agent, the Designated Control Agent, and the Focal Points together form a Language Control Board which is chaired by the Language Control Agent. The Board's function is to review and make recommendations regarding proposed changes to the JOVIAL language standards.

A JOVIAL user is any person or organization which uses or contemplates using JOVIAL. These users are organized into a users group which provides a forum for discussing language issues; provides solicited and unsolicited inputs on language changes, subsets, user experience with the language, compilers and support tools; and reviews and comments on proposed revisions, to the language standard, made by the Language Control Board. The Users Group will elect its own officers, and therefore will be relatively independent of the control mechanism itself.

HQ USAF is in the chain because when an Air Force organization or system developer wishes to use a HOL not approved for Air Force use (as per Air Force Regulation 300-10), HQ USAF will have the final decision on whether or

not that wish will be granted. HOLs which require such a waiver from HQ USAF are subsets of Air Force approved HOLs, other non-standard dialects of Air Force approved HOLs, all HOLs not listed in AFR 300-10 (whether or not those HOLs are approved via Department of Defense Instruction 5000.31) and PL-1. PL-1 is singled out because while listed in AFR 300-10, it is *not* approved for defense systems.

Although there are numerous details which describe the inner workings of this control mechanism, they will not be elaborated on here with the exception of the mechanism for proposing changes to one of the standard JOVIAL definitions. All requests for language changes will be submitted to the Language Control Agent for review. The Agent will then submit the proposed change to the User's Group for review and comment. The change request, and the results of all prior reviews will then be provided to the Language Control Board who will make a recommendation to the Designated Control Agent, and simultaneously provide that recommendation, which includes detailed syntax and semantics if necessary, to the User's Group. The Designated Control Agent will use the Board's recommendation and the inputs of the User's Group to arrive at a final decision regarding the proposed change.

A comparison of the Air Force's approach to JOVIAL standardization and the United Kingdom's (UK) procedures for standardizing on and controlling CORAL 66 may give the reader an appreciation for some of the finer details of the Air Force approach, since CORAL 66 remains one of the best military HOL standardization efforts. Neve (NEVE1) gives a concise description of the history and status of the UK's standardization on CORAL 66 for real time military systems, and is the prime source of the CORAL 66 data related here.

Neve points out that "By the end of 1966 . . . , there were three essential ingredients necessary for the establishment of a language standard". All three of those ingredients parallel the situation with regard to JOVIAL:

- (1) Top management within the Ministry of Defense (MOD) recognized the benefits of software and hardware standardization and provided a policy decision favoring the adoption of a HOL standard.
- (2) The technical people needed a well defined standard to test compiler generation methods. In the case of JOVIAL, there are also other HOL support tools that require a firm specification to be cost effective.
- (3) There was an existing language, CORAL 64, similar to JOVIAL, which was a suitable starting base for the standard.

The CORAL 66 specification was not frozen for some years, and Neve warns "The temptation to freeze the specification too early should be resisted". This is part of the reason for the language change mechanism in the control of JOVIAL, but unlike the situation with CORAL 66 which was frozen (i.e. *no* further changes) in 1970, it is not planned to freeze the JOVIAL specifications at any time.

The CORAL 66 control mechanism includes an official technical body, like the JOVIAL Language Control Board, which addresses technical issues and proposals regarding the language, as well as a technical organization, like the JOVIAL Language Control Facility, which validates and certifies compilers. Since no changes are allowed to the language, a CORAL 66 compiler is "certified" forever. Because changes may come to JOVIAL, it was decided to revalidate compilers for each specific use to ensure the latest version of the language is used.

The CORAL 66 control mechanism and the MOD do *not* deal directly with the development of CORAL 66 compilers. MOD system builders are free to select from many computers on an approved list, but an essential requirement to get on that list is a certified CORAL 66 compiler maintained by the hardware vendor. A waiver is required for the use of any non-approved computer and HOL.

Historically, DOD has been directly involved with compiler development/procurement, and until the standardization effort is mature, it must continue to do so. Hence, the Language Control Facility will assist DOD users in procuring and maintaining JOVIAL compilers. At the time of this writing, industry has taken the DOD direction seriously enough to initiate its own compiler developments. Rest assured that the JOVIAL mechanism is intended to and prepared to support and control both DOD and other sponsored compilers.

Encouraged by the success of the CORAL 66 standardization and control efforts, and by standardization advantages claimed by the three services in DOD, the planners for the DOD Common HOL, intended to eventually replace all "DOD-unique" HOLs like JOVIAL, have definite ideas for controlling their resulting language. Although nothing is official as yet, it is planned to place strict controls on that HOL (similar to those on CORAL 66) yet provide a variety of user services and support (similar to those available for JOVIAL users).

BENEFITS

This paper thus far has only indirectly referred to any benefits that may accrue from HOL standardization. Neve (NEVE1) states that certain benefits became apparent after a few years of CORAL 66 standardization, so rather than provide conjecture about potential benefits, the following are taken directly from his paper verbatim, and without comment:

- (1) "The time taken to implement systems is reduced."

- (2) "The output of programmers is increased."
- (3) "The standard of documentation is higher and the program structure more visible."
- (4) "Systems are easier to hand over to the user since they will be in a language understood by all involved parties. This results in reduction in the time taken for handover."
- (5) "Systems can be more easily maintained by the user."
- (6) "Systems can be more easily extended or modified by the user, rather than by the contractor, whose original team is probably dispersed anyway."
- (7) "Estimates of software cost and development time can be assessed better, based on cumulative experience."
- (8) "The time to train key servicemen is reduced and rationalized."
- (9) "Programmers become more transferable and thus fit in better with service requirements."
- (10) "Some degree of program transferability may be achieved."
- (11) "The adoption of such a policy imposes a degree of rationalization in the procurement of computers for defense."
- (12) "There is a consequent reduction in spares backing and specialist test equipment."
- (13) "There is a consequent reduction in the need for skilled manpower, which is hard to recruit and retain, to have knowledge of a wide range of computer hardware."
- (14) "Some degree of interchangeability of hardware modules is achieved."

It's too early to give a measure of success for the DOD or Air Force HOL standardization programs. When the day comes to assess that success, it may be very difficult to provide accurate quantitative data to the decision makers who will decide the future fate of these programs. These people will want to know not only what it cost, which is measurable, but what it saved, which is elusive. If a defense system comes closer to cost, schedule, and expected performance because of HOL standardization, who will brag? If a system developer felt that standardization is a thorn in his side, he will be most vocal.

Recognizing this dilemma, the Air Force has set up its control mechanism with service to the user as a primary concern, and will examine its mechanisms and policies and their effects on a yearly basis. In this way, negative and positive aspects can be rectified and reinforced respectively, and both qualitative and quantitative data can be recorded while still fresh.

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DISCUSSION

Jaeger

How can the process of HOL-standardization be initiated in an international/interorganizational framework? May AGARD be an appropriate platform?

Author's Reply

The people behind the common DoD programming effort known as "DOD-1" are pursuing international standardization of that language. There presently exists some international standardization committees however standardization through that process is progressing rather slowly. The DOD-1 people have sought and received active support of the language development from the UK, Germany and France. AGARD could most definitely be a platform for such international-interorganizational standardization.

Jaeger

Are the more recent developments (e.g. PEARL) more promising candidates for standardization than the better known, however possibly less powerful HOLs?

Author's Reply

Technically speaking, the newer HOLs are better candidates for standardization. However, their lack of general availability on common hardware can be a deterrent. Unfortunately, historically most HOL standardization efforts have given little consideration to the technical issues. It is difficult to achieve standardization within even a single organization such as the USAF.

Y.Brault

In the future there will be a need for interoperability in NATO. Can you comment on attempts made to reach standardization of HOL in NATO countries?

Author's Reply

At the present time the only effort that I know of is semi-official. That effort is the UK, German and French involvement in DOD-1. I do feel that HOL standardization is a necessary requirement for interoperability but certainly not a sufficient condition.

A.J.Maher

It was indicated that the USAF encourages users to employ the standard Jovial language. From our perspective, permission to use a subset of the large J73 language would be an inducement to use Jovial. However you indicate that the Air Force prohibits the use of a subset of the language. Can you expand upon the rationale of this apparent inconsistency?

Author's Reply

Very rarely has a subset been a "true subset". Portability of software and programmers would be hurt by many subsets which are not contained in one another but have features not in common, e.g., A, B, and C could be subsets of D; but none would be a subset of the other. This would obviously cause increased overhead in managing the standardization process.

A. Clearwaters

What about standardizing the services for multi-tasking and other OS functions.

Author's Reply

Right now we don't really know enough about multi-tasking to settle on a standard. With regard to the other OS functions a common Job Control language was once attempted and failed. The DOD-1 HOL will define the environment within which it must operate. It can operate in a "vacuum" of OS functions but then the "compiler" would provide the environment.

PROJECT WAVELL

The Command and Control Information System for the British Army

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SUMMARY

This paper describes Project WAVELL, the battlefield Command and Control Information System produced by The Plessey Company Limited for the British Ministry of Defence (M.O.D.). The paper outlines the origins of the requirement, the procurement policy specified by the M.O.D. and the configuration and functions of the system. Current activities and future plans are also described.

1. INTRODUCTION

1.1 The Name WAVELL

The name WAVELL is a codeword used to facilitate reference to the WAVELL system and it is also the name of a British General.

1.2 The Project's Aim

The aim of the project is to provide ADP assistance to the staff in formation headquarters in 1st British Corps, British Army of the Rhine (BAOR), to help them carry out their command control functions. The problems of command and control on the battlefield have been the subject of studies and research for many years in many parts of the world and the main conclusion which has been universally arrived at is that the problem is extremely complex.

2. THE OPERATIONAL REQUIREMENTS

2.1 Improved Efficiency

It is well known that in a battlefield environment a substantial proportion of staff time and of available communications facilities, is spent on handling routine information, the greatest part of which is concerned with locations. This information is acquired, disseminated and subsequently confirmed by using combat net radio or trunk communication. The proportion of time and facilities spent in these activities is likely to increase as warfare becomes more mobile, and as improved surveillance systems increase the amount of information generated for assessment by the staff. ADP assistance is expected to substantially improve the efficiency with which staff can retrieve, assess and disseminate battlefield data.

2.2 Enhanced Continuity of Command

Another battlefield command and control problem area is that of maintaining continuity of command during mobile warfare. ADP facilities are expected to substantially reduce the time taken to update the 'Step Up' and alternative headquarters which are the basis of that continuity. The current manual systems are inevitably slower than is desirable, and the effectiveness of the process is limited by delays in updating a headquarters echelon on arrival in a new location. ADP assistance should simplify and speed up the updating process and allow changes of command to take place more rapidly, thus matching the mobility of the fighting troops.

2.3 The Pilot Scheme (Stage 1)

The potential benefit of providing ADP assistance was agreed within the British Government's Army Department in the Spring of 1976. This led to a decision to implement a limited pilot scheme to test the viability of such a system and check out the basic assumptions. It was recognised that such a system would be confined to providing assistance with the handling of routine information, speeding up the dissemination of information and ensuring that all headquarters were operating on the same basic data. The task of map updating would also be eased.

The problems associated with developing and implementing such systems have been studied by the Plessey Company and the British Ministry of Defence for many years, and early attempts to define fully the requirements invariably revealed their almost unbounded complexity. Consequently it was decided that the problem must be solved by evolution from a simple base, and thus was established the policy to buy basically commercial equipment 'off the shelf', bring it into service quickly and develop it as experience was gained. This was thought to be probably the most cost-effective approach to defining the ultimate system in the long term, and subsequent events have confirmed the soundness of that policy.

2.4

Summary of Benefits

In summary the proposed system was expected to yield the following overall benefit: it should release the staff for the more important tasks of assessment, evaluation, decision making and issuing orders. In addition it was anticipated that the automatic dissemination of information would increase the availability of telephone channels on the trunk communications network, and this indirect benefit would improve voice communications between headquarters echelons and speed-up the passage of orders and other high priority information. Furthermore, the staff, having gained practical experience of ADP, would be able more realistically to state their full requirements for the definitive system that would follow the pilot scheme. Initially, however, WAVELL was to be a simple information storage and retrieval system with a distributed database, the elements of which were to be synchronised automatically, using the currently available BRUIN trunk communications system as a bearer.

3.

IMPLEMENTATION

3.1

Summary of Implementation Problems

At first sight the task of providing an ADP system for the army based on existing 'off the shelf' commercial equipment may appear simple. There is, after all, nothing very difficult in providing a computer and backing store to present information on visual display units or hard-copy printers. Project WAVELL, however, does involve solving a number of other problems which to date have frustrated the efforts of some of the best system designers around the world. For a start the system must survive the battlefield environment.

The problems of extremely rugged cross-country shock and vibration requirement, extremes of temperature and humidity, very limited space, and the uncertainties of field power supplies, are particularly challenging when considering basically commercial equipment. In addition many of the equipments must be readily demountable from their vehicles for deployment in barns, cellars or tents, and easily handled by soldiers under extremely adverse conditions - total darkness, rain or snow for example.

3.2

System Configuration

Figure 1 illustrates the basic elements of a simple information storage and retrieval system. In WAVELL such elements are installed in operational army vehicles to provide an ADP capability at each echelon headquarters. Each headquarters has its own database held on disc backing store, viewable by staff users with the aid of the central processor and visual display units.

Such a capability at individual headquarters has, in fact, been shown to be quite useful by itself; however, the real problems of command and control on the battlefield stem from the need for commanders and staff to have an up-to-date and closely similar picture of the battle wherever they may be located.

The WAVELL system is therefore required at all times to maintain the databases of headquarters distributed across a large area of country, in close synchronism. By this means decisions of Commanders and staff may be more accurate and more timely, and change of command when required can be achieved much more quickly and efficiently than is possible at present. In addition the system eliminates many routine and time-consuming tasks. To achieve all this a fast, secure digital data network linking all the processors and their databases is essential.

Figure 2 shows a typical part of the network provided for WAVELL Stage 1. Corps and divisional headquarters locations are shown as squares and at each of them a WAVELL system has been provided. These are mounted in standard army 3-ton containers or shelters (indicated by the larger squares) as currently used in BAOR, and as a temporary installation for Stage 1, in Landrovers at the new armoured Task Forces, as indicated by the oblongs.

3.3

Equipment (Container Installation)

The equipments in the installation are shown in Figure 3.

The processor, produced by Plessey Peripheral Systems Limited, is based on the Digital Equipment Corporation PDP 11/34, and is capable of addressing up to 128-thousand 18-bit words of core memory. A fixed head disc random access backing store is used, having a capability of storing up to 40Mbits of data. A system control printer is provided for the operator, and patch panels and line drivers for the connection of remote visual display units and printers.

Exchangeable 20Mbit four-track magnetic tape cartridges are used for software and database loading.

The interface to the communications network is provided through a multiplexer and the vehicle is also provided with an air conditioning unit (not shown in the diagram).

Figure 4 is a picture of the interior of one of the Stage 1 Divisional headquarters vehicles showing the processor, disc, control printer, tape drive and patch panels.

3.4

Equipment (Landrover Installation)

The Landrover system for the more forward headquarters contains similar equipment - but rather less comfort for the occupants (Figure 5). Here too there is a system control printer and keyboard, patch panel and line drivers, and a cartridge unit for loading the programmes and the database. For the second stage of WAVELL this installation

will be provided in armoured vehicles. These systems provide similar functions to the larger installations but are designed for more forward deployment and to match the greater mobility of command at this level. Air conditioning equipment is provided on the top of the vehicle. Figure 6 shows the interior of one of the Stage 1 Landrovers.

3.5 Deployment

To help visualise how WAVELL systems are deployed, the non-tactical artist's impression shown in Figure 7 illustrates the basic elements of the system in use. On the hilltop the nodes of the communications network (the Communications Centres) Landrover mounted systems are deployed alongside the existing Commcen equipment, to provide a switching capability for routing data through the communications network to and from the various headquarters as, for example, shown in the picture. The network itself is constructed from UHF radio links using the existing BRUIN communications equipment already deployed in BAOR for voice, telegraph and facsimile communications. WAVELL uses a dedicated 4.8Kbit digital data channel throughout this network. It must be noted, however, that WAVELL itself is not a communication system.

This communications network is subject to frequent and often unpredictable reconfiguration to meet operational needs and changing tactical situations. As with all such systems the links from time to time are susceptible to interference in varying degrees, including jamming and destruction by enemy action. Redundancy in the network and the provision of alternative paths is therefore an important consideration, as is the detection and correction of errors in the data. Data is divided into small messages, or packets, to increase the probability of successful transmission through the network.

The problems of controlling such a network are complex and the WAVELL vehicle illustrated on the left in Figure 8 provides the system control facilities which are essential to the successful management of the system. Also shown in this illustration is a WAVELL display unit in a staff vehicle (on the right) being used in close conjunction with the all-important map. It is not feasible at this stage to provide automatic map display facilities although much work is in hand in different parts of the world to find a cost-effective solution.

3.6 Major Technical Problem Areas

The successful implementation of the project has been critically dependent upon the resolution of problems in two major technical areas:-

- (a) The management and control of the databases through the system and
- (b) The provision of an efficient communications system for fast, robust message switching.

The details of the software design used in these two important areas cannot be described in this paper for security reasons. Suffice it to say that the protocols for database and communications management are required to be such that data is never lost. In practice it has been found that digital information can be successfully distributed when adequate voice communication is not possible. The network is continually monitoring and updating its own connectivity, and at any time each processor is aware of the total network connectivity and may select the optimum route to any destination.

The design and development of the software for this system has been without question a major undertaking and the most difficult part of the whole programme. While 'off the shelf' software such as the RXS11 operating system has been used in the development programme, the majority of the software has been tailor-made for the application. The software is written mainly in CORAL, the language preferred for real time systems by the Ministry of Defence and the now well established 'top down' approach has been followed for the system design, followed by implementation from the bottom (or module level) upwards. The total number of man-years spent in the production of Stage 1 software has been approximately 70.

3.7 Summary

In summary then, we have provided in an extremely short timescale a complex software system and a set of rugged, mobile systems, capable of maintaining synchronised distributed databases, across a volatile and error-prone communications system. The system operates in a hostile electronic and physical environment. As far as is known such a system has not been successfully achieved anywhere in the world before, and it is believed to be the first effective battlefield command and control system to be deployed in the field.

4. TIMESCALES

4.1 Overall Development Programme

The timescale in which all this has been achieved is very short indeed, but it has still been necessary to compress into it the essential processes of feasibility study, project definition, system design and implementation. These stages in the systems procurement cycle are normally carried out sequentially and often over a period of many years.

The tight timescales which have had to be met are illustrated in Figure 9. From the summer of 1976 just 15 months were available to build the system and make it available for UK Trials with the Army's BRUIN communications system in the Autumn of 1977. Those trials were completed on time early this year, and the Stage 1 system was shipped to BAOR for use on operational exercises during this summer. All the development work and trials during

this period, and the user trials in BAOR are called Stage 1. The equipment supplied during this stage equips just one division of 1st British Corps, plus the Corps headquarters. After a period of continuing evaluation in BAOR further deployment of fully operational equipments for the whole of 1st British Corps (Figure 10) will occur in the early 1980s.

The prospect of achieving a timescale such as this, rather like the prospect of imminent execution, has concentrated minds wonderfully on the resolution of operational, technical and managerial problems. It has demanded an exceptionally high level of understanding and co-operation between customer and main contractor, and this has been a major factor contributing to the success of the project.

5.

CONCLUSIONS

In Stage 1 the general concepts of Project WAVELL have been shown to be sound, and it has been proved that a system comprising processors based at headquarters locations, maintaining synchronised distributed databases using battle-field trunk communications is both feasible and viable. Most important of all, the army staff user finds the system to be of considerable benefit. The step which has to be made from Stage 1 to Stage 2, is simply to upgrade the environmental and performance specifications of the system hardware and to optimise the software design. The Stage 2 system will be to full military environmental specifications using a more powerful processor, and solid-state backing storage. The staff facilities to be provided will initially be the same as those provided in Stage 1. During its operational life it is, however, anticipated that the facilities will be extended into additional application areas such as logistics, engineering and artillery and maybe one day it will be possible also to include an inexpensive fully interactive multicolour map display.

ACKNOWLEDGEMENTS

The author wishes to thank the Plessey Company Limited for permission to publish this paper and to acknowledge his many colleagues whose efforts contributed to the paper.

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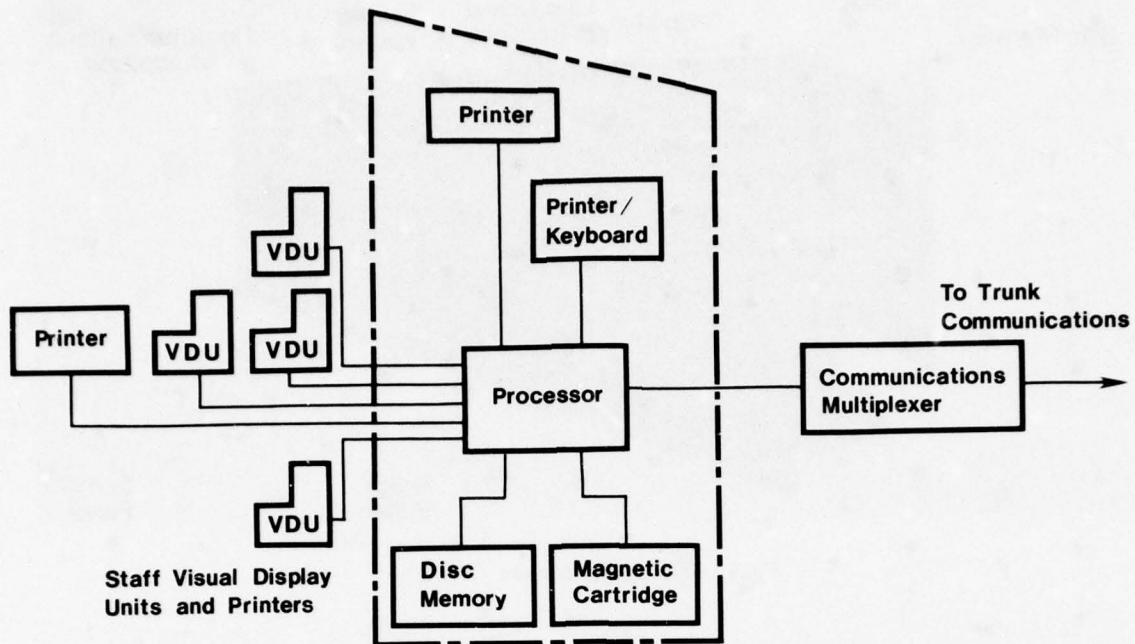


Fig.1 Typical system configuration

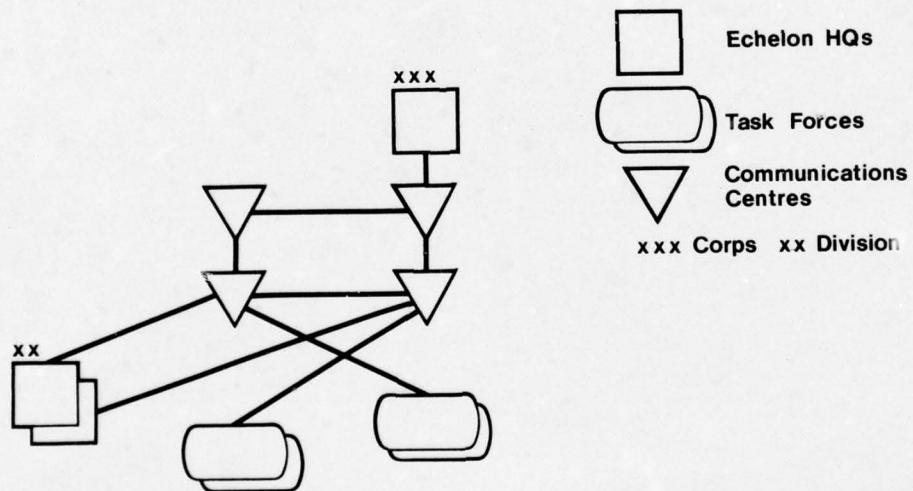


Fig.2 Stage 1 system diagram

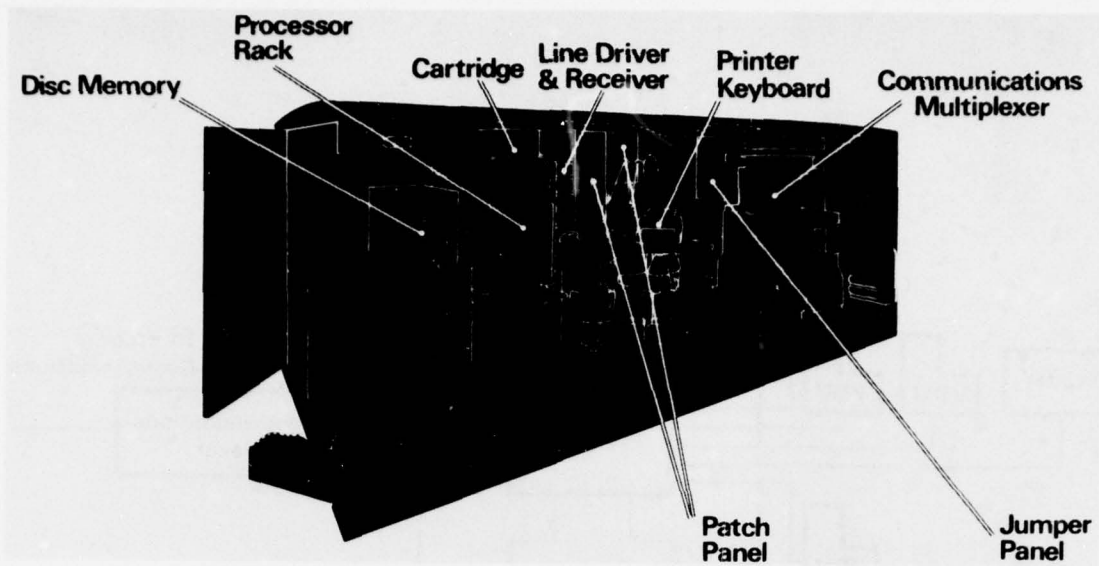


Fig.3 Processor installation – container

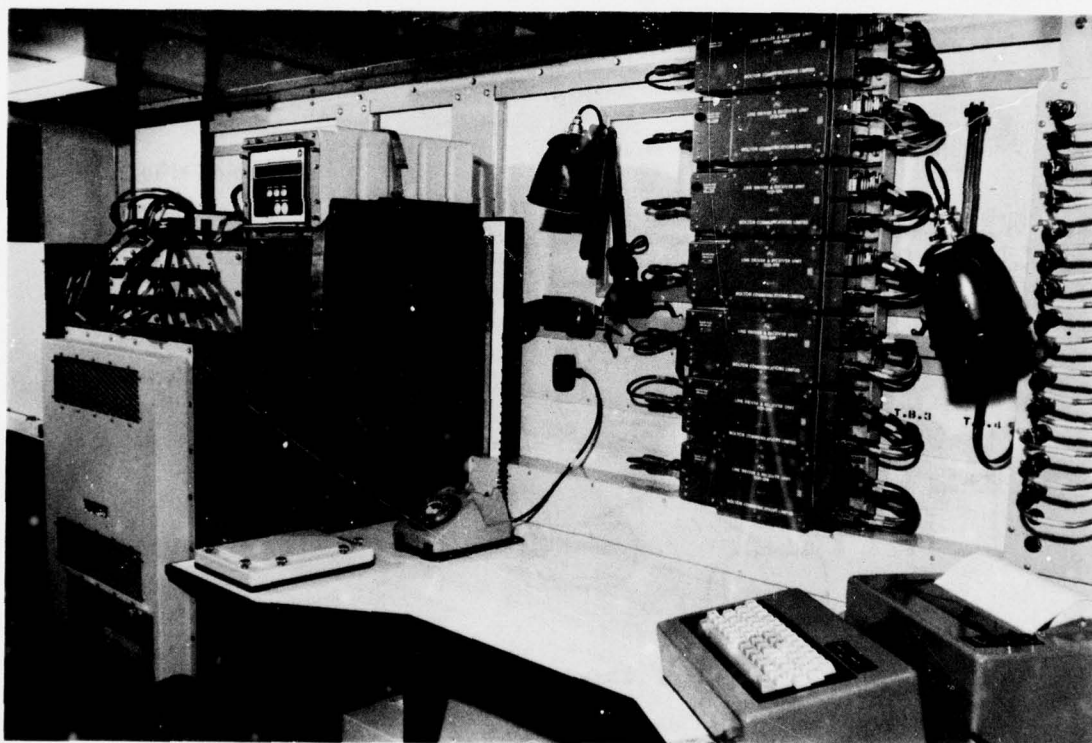


Fig.4 Interior of Stage 1 Divisional H.Q. vehicle

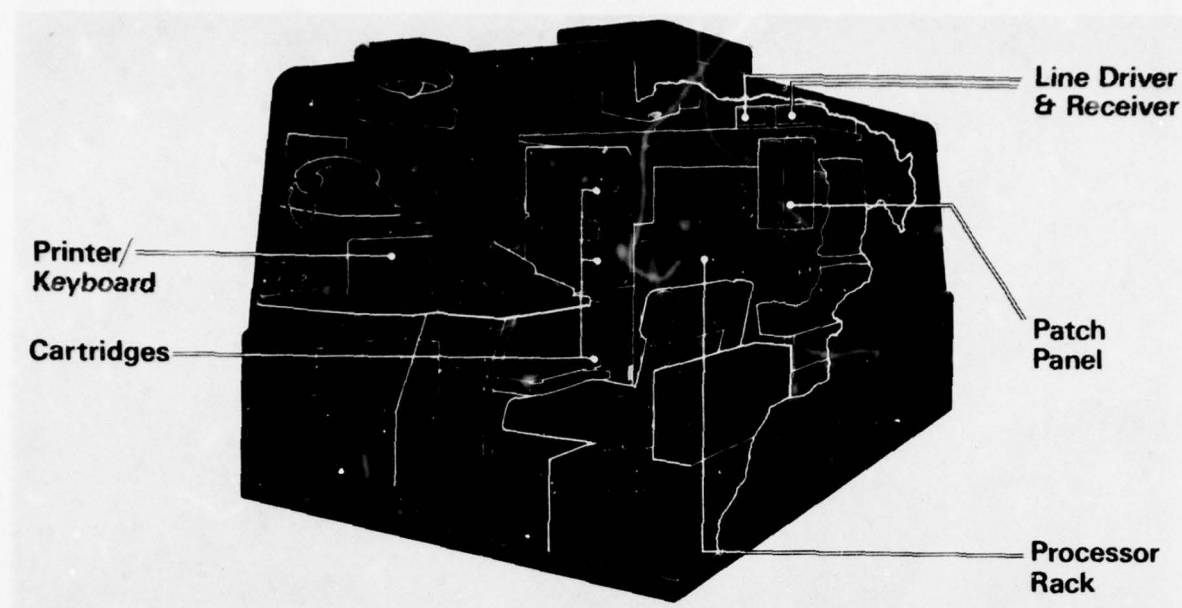


Fig.5 Processor installation — minor system

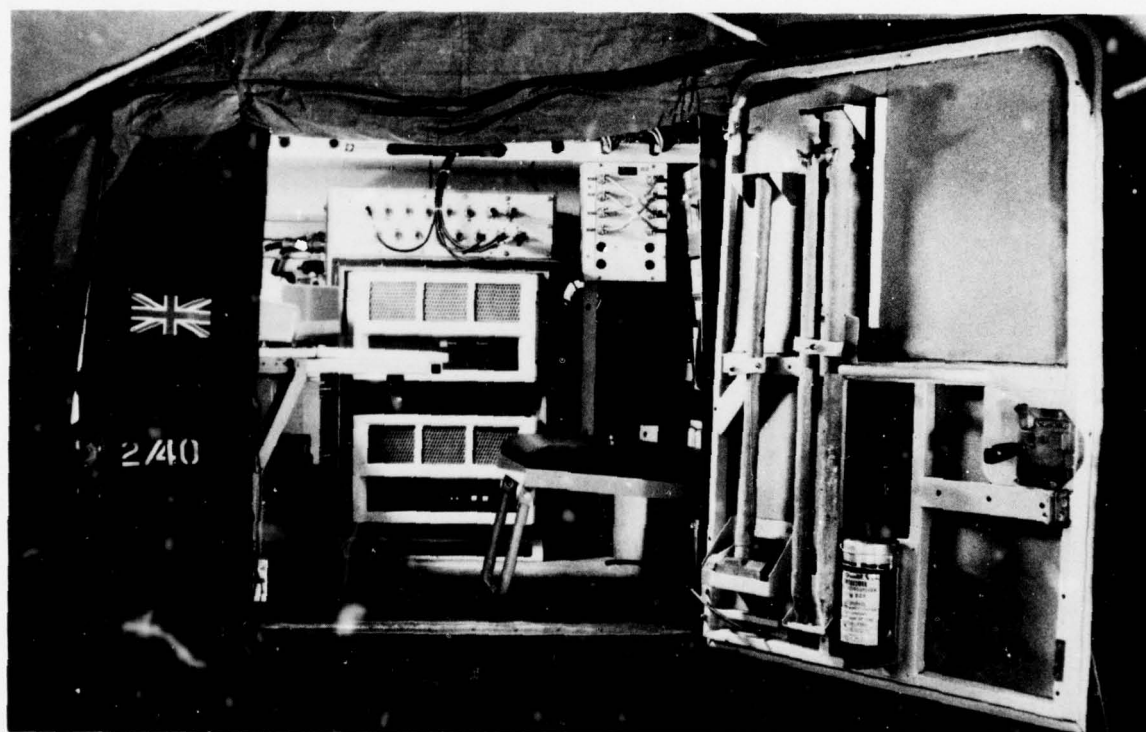


Fig.6 Interior of Stage 1 Landrover

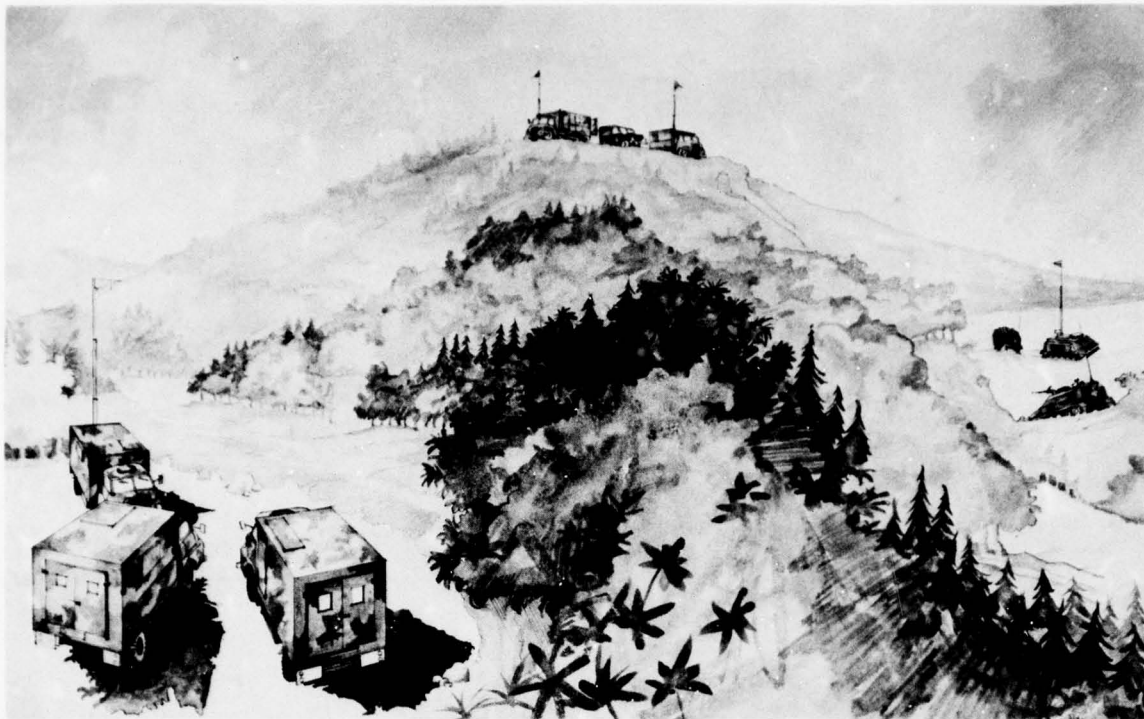


Fig.7 Deployment

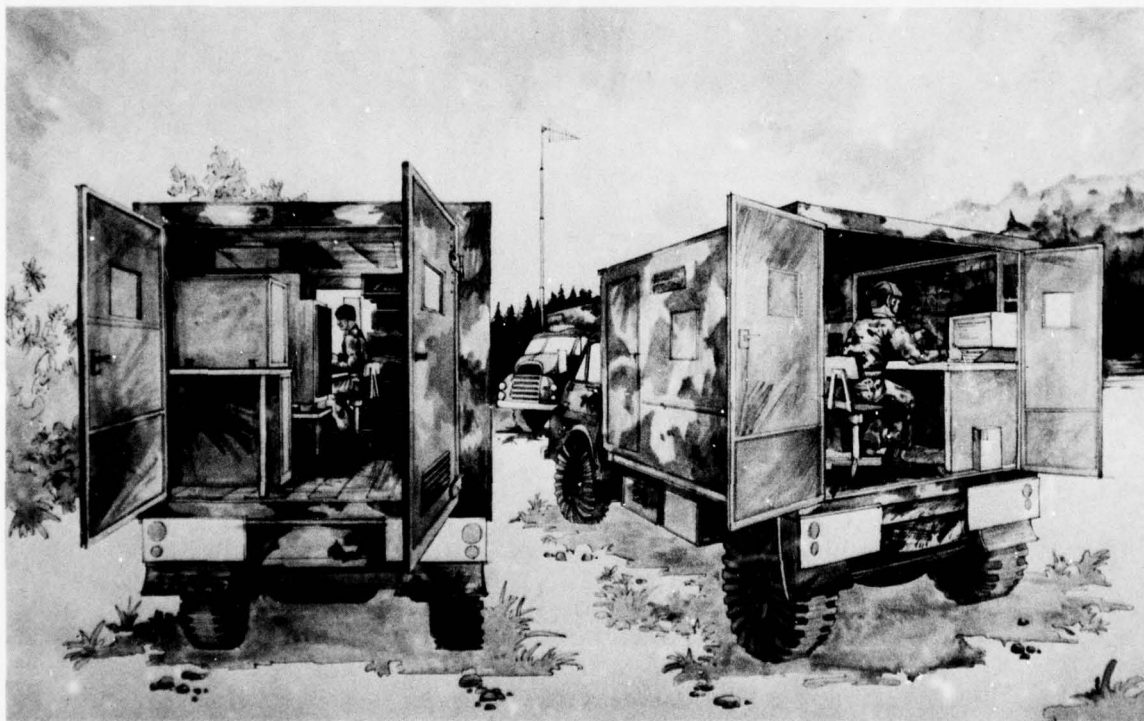


Fig.8 System control vehicle (left) and staff vehicle (right)
with WAVELL display unit

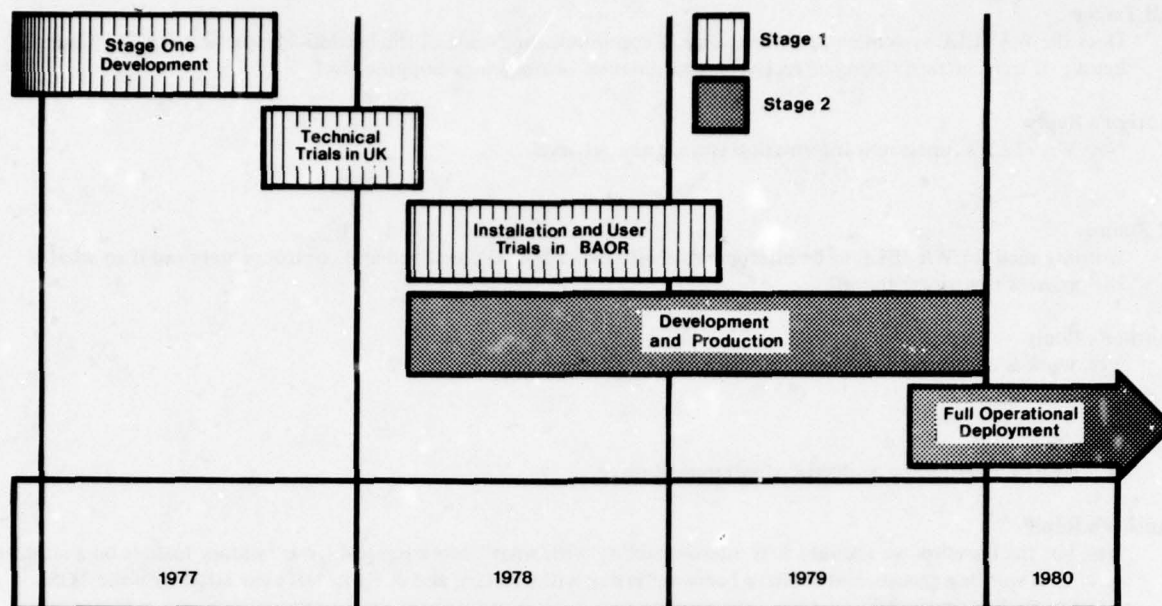


Fig.9 Implementation

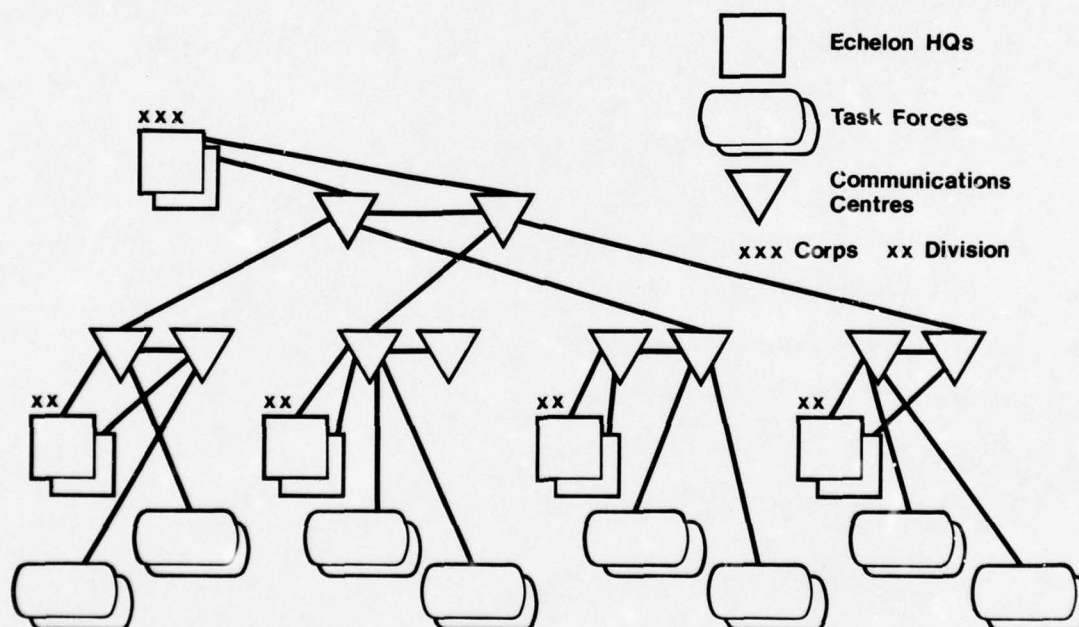


Fig.10 WAVELL system diagram

DISCUSSION

J.B.Tasche

Does the WAVELL system control the technical communications side of the battlefield situation, e.g. the timing, keying of transmitters, timing of receivers, coordination of frequency-hopping etc.?

Author's Reply

No. WAVELL's function is information storage and retrieval.

R.Zimmer

Is it intended for WAVELL to be interoperable with other NATO command and control centers and if so what is the progress towards that end?

Author's Reply

Yes, work is currently in progress and discussions have been ongoing.

Question

Is WAVELL considering problems of interoperability?

Author's Reply

Yes, but the question we should ask is interoperability with what? More seriously, our military team is on a number of NATO working groups, and we have been conferring with military and civilian staff associated with the TOS programme here in the US.

MOBILE TACTICAL C³ SYSTEMS

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SUMMARY

In 1968 the writer presented the keynote address at the first "Technology for Data Handling in Tactical Systems" meeting of AGARD. The basic tenet was that tactical air command and control would need to emphasize physical survivability through a net of mobile, decentralized systems.

Now, ten years later, the need still exists and remains to be satisfied. Indeed, it is now clear that anti-jam communications must be added to the list of requirements.

Fortunately, the growth in technology predicted ten years ago has been achieved or exceeded. The concept of the previously described "1975 System" can be built today.

This paper describes an updated version of the mobile, survivable C³ concept. The basic building block is a modular van housing intelligent terminals, a miniprocessor with high-density mass memories, multiplexed internal wiring to permit rapid changes of equipment, and an anti-jam communication system.

INTRODUCTION

Ten years ago I presented the keynote address to the AGARD meeting on "Techniques for Data Handling in Tactical Systems." A system of mobile, tactical C³ systems was proposed to provide effective, survivable command capability. Technology developments to support this concept were also recommended.

In the ensuing ten years the need for such mobile C³ systems has been further substantiated, and the technology to provide the system design has matured.

The keynote speaker for this meeting, Dr. I. Mirman, has addressed the reasons for the slow progress in survivable C³. I will, therefore, concentrate on a rationale for achieving the needed capability.

PRIORITY OF REQUIREMENTS

Listing basic requirements for a mobile, tactical C³ system is a relatively straight-forward task; assigning priorities, on the other hand, becomes a more subjective (and debatable) matter. The prioritized list below is discussed briefly in the following paragraphs.

1. Survivability
2. Affordability
3. Preplanning
4. Flexibility
5. Interoperability
6. Capability

1. Survivability

The considerations since the 1968 AGARD paper that raise survivability to the highest priority are:

The lessons of the last war in the Middle East, including the vulnerability of C³ to physical attack and electronic countermeasures.

Strategic analyses that conclude that NATO must cope with PACT use of nuclear weapons (see Richard Pipes, "Why the Soviet Union Thinks it Can Win a Nuclear War," Air Force Magazine, Sept. 1977).

The dearth of truly hardened or truly mobile C³ systems in NATO.

The growth of "Red Brigades" which pose a serious sabotage threat.

The overwhelming historical record of successful surprise attacks despite strategic intelligence that an attack was imminent. Pearl Harbor has had many counterparts before and since its occurrence.

One must then conclude that a PACT attack could achieve tactical surprise, could include nuclear weapons, could place high priority on destroying NATO C³, could be aware of the location of NATO C³ assets, could use massive electronic warfare measures, could exploit coordinated sabotage attacks, and could - unless there is a significant change - have a high expectancy of crippling NATO C³.

If NATO C³ is to be a factor in deterring a PACT adventure, or failing this, provide effective control of NATO forces, then NATO C³ must be able to survive as an effective mechanism.

To survive, NATO C³ must be:

- a. Protected against CBR weapons
- b. Truly mobile
- c. Greatly dispersed
- d. Difficult to identify and target
- e. Defended against aircraft, missile, and ground attack
- f. Or some realistic combination of the above.

2. Affordability

If, despite the multi-billion dollar investment in C³ to date, NATO lacks a survivable C³ capability, the cost for achieving survivability must be affordable. With the quantitative balance of weapons such as tanks, artillery, etc. heavily in the favor of the PACT nations, allocation of funds for survivable C³ will be difficult. Therefore, it is necessary to make maximum use of standardization, moderate performance demands, and existing military and non-military resources to achieve affordability. C³ systems must be designed to meet affordable production costs (DTUPC).

3. Preplanning

If it were possible to preplan for every contingency, encapsulate the plans in a suitcase, and provide every commander with such a suitcase (suitably protected against loss to the enemy, of course) survivable C³ would be a trivial challenge. Unfortunately, even with the microprocessor revolution, this is not possible. What is possible, however, is the exploitation of superior knowledge of terrain features in our NATO countries, preselection of counter-attack sites such as choke points, and preplanning of cooperative attack at these points should the opportunity arise. Such plans can be stored in a small C³, in aircraft, in tanks, and perhaps even in a suitcase. Formulation of the contingency plan directive could then be accomplished using many modes of communications in the face of even an unusually high level of enemy countermeasures. The first rule in anti-jam is to require the least amount of data be transmitted over the widest bandwidth and most numerous independent communication systems. Preplanning helps to achieve this ideal.

4. Flexibility

The impracticality of the "plan-for-any-contingency-in-a-suitcase" stems from the infinite number of possibilities once a war begins.

If, for example, the PACT forces spare NATO cities in the hope of capturing their manufacturing capability, then the survivable C³ must be able to exploit cities as a haven. To do so they must be able to communicate while hidden in a building. This is a different problem from communicating in the open.

If the C³ must move continuously to survive, this is a different communication problem than when stationary.

If the C³ element is a part of a dispersed, internettted C³ system, the element must be reconfigurable by software to assume the role of another C³ element which is on the move or which may have been destroyed.

No doubt, many other examples of flexibility will come to your mind that could enhance the ability of the overall NATO C³ system to meet unforeseeable contingencies.

5. Interoperability

By presidential edict, we in the U.S. are placing great emphasis on the interoperability of NATO forces. We heartily concur with the importance of interoperability, but in addition to our language differences, we have such differences in our communication systems that they do not interface properly.

Exchange of personnel carrying their nation-peculiar communication sets may be a cumbersome but adequate solution in our present system of large fixed or "moveable" C³ centers. It is impractical if we turn to a system of dispersed, small, mobile C³ units in order to achieve survivability.

The most promising solution is the use of common communication equipment, frequencies, modulation, and a common military language (through the common language may be translated on a display into the user's national language).

6. Capability

It may be very strange to place capability at the bottom of the priority list but this may be the price of having any capability at all after a surprise attack takes place.

Perhaps it might be more palatable to state that we need to prioritize desired capability so we can distinguish between what is most vital and what is merely "nice to have." By now you will have realized I am repeating my theme of ten years ago: modularized, mobile C³ units serviced by suitable communications. Even though

technology predictions of ten years ago have come to pass, we still have a propensity of putting 100 kg of potatoes in a 10-kg bag. To achieve our objectives we must be highly selective in specifying capability requirements.

Before describing my perception of the survivable, mobile, modular C³ system of the future, I would like to show you a short film extract which describes a demonstrator system built by RCA to develop an optimum RPV command center concept. It will serve to clarify some of the concepts I will describe later. The RPV mission is actually compatible with my basic theme of survivability since the RPV could be anything from the mini-RPV to the Ground Launched Cruise Missile - all of which are designed for survivability.

BASELINE CONCEPT

To meet the survivability and other objectives, I suggest that a family of van-based mobile centers be developed using common equipments, tailored for individual missions by software. The basic van would be useful for the NATO theatre or for crisis situations. For some applications the center could be contained in an armored personnel carrier.

A commonly used van (2.46 x 2.46 x 6.15 meters of 8 x 8 x 20 feet) is suggested as the means by which identification could be avoided. The van can be mounted on a flat bed for mobility, can be concealed in wooded areas or urban areas (e.g., moved into a garage) and can be carried by cargo aircraft.

Each van would contain the following:

1. Two or three "smart" terminals
2. Miniprocessors
3. Mass memory storage
4. Communication terminals
5. Auxiliary power units and necessary environmental equipment
6. Mission-unique equipment, e.g. radars
7. Built-in test and training

Different C³ organizational levels; i.e., in the U.S. Air Force, TACC, DASC, CRC and FACP, would use a number of the basic vans appropriate to their mission. The vans making up a center would, however, require the capability of working together while separated. Survivability is the driving force to avoid identifiable clusters of vans. Should a van be destroyed, its essential duties should be accommodated in the surviving vans.

A more detailed discussion of the equipment in each van follows to indicate how the proposed universality could be achieved:

1. "Smart Terminals"

There is a wide variety of terminals in use or in development. Yet the elements are the same: computer-driven displays and entry devices. It seems extremely wasteful to start from scratch every time with new terminals in an era when they can be tailored by software for different functions. We believe that the behavioral scientists have provided a reasonably clear set of guidelines on how one should human-engineer a terminal with almost universal flexibility. It could take the following form for our proposed van application.

Two displays per console - one for alphanumeric and one for graphics or video. The alphanumeric display would be computer-driven to provide the information the operator selects. It should be in color to indicate items of priority. For example, a display listing status of individual aircraft could use red letters for aircraft out of commission, yellow for in-use, and green for ready aircraft.

The other display would be used for graphics, maps, pictures and as a video terminal for closed-circuit TV linkup between the vans that together make up a C³ system despite dispersal for safety. Again, color should be used to make the operator's job easier; e.g., a different color for friend or foe.

The size of the displays is a tradeoff between resolution and space limitations in the van. A twelve-inch diagonal size is a reasonable compromise.

Since the displays are computer driven, additional aids can be provided the operator:

- a. Fluctuating intensity or color to attract attention
- b. Electronic zoom to magnify selected areas
- c. Change or motion detection

The suggested entry system is a combination of:

- a. Menu-type keyboard
- b. Light pen, speed ball, or joy stick

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The menu-type keyboard provides the means for customizing the terminal for the gamut of operator duties for the different positions in the C³ system (i.e., TACC and CRC). Yet it does so with a minimum number of keys. For example, the top row is tagged with the highest level functions for the operator. When he selects one of the keys, say "enroute control," all the other keys in the keyboard are computer-controlled to have titles pertinent to that function.

Light pens, speed balls, and joy sticks are proven devices for quickly addressing the computer and obtaining desired actions.

2. Minicomputers

The advent of large scale integrated arrays and microprocessors make possible high-capacity data processing in small weight and volume. Certain of the technology, for example, CMOS/SOS, also require modest power, generate modest heat, and have inherent nuclear hardness.

Using these new processors means each van can be given its own computer instead of today's practice of using a central computer. This permits enhanced survivability through redundancy. Furthermore, redundant computers in each van should be provided for reliability.

3. Mass Storage

Disk storage devices can provide mass memory but are bulky. Bubble and CCD memories are now rapidly evolving. These technologies should be pushed to provide an adequate capacity. A measure of adequacy is the ability to store the data necessary to permit the van to perform the duties of a destroyed van as well as its own.

4. Communication Terminal

Internal van communications should include voice and video. A data bus should be used to link all of the equipments in the van and to provide for easy retrofit of new generation equipment as it becomes available - and necessary. The next task is to provide communications to link the vans together while on the move or when dispersed over an area approximately one mile square.

While on the move, low-power, millimeter-wave communication using steerable, directive antennas could provide bandwidth adequate for video and permit adequate data exchange. The low power (milliwatts) is to minimize enemy detection. When the vans are parked, fiber optics are very attractive interconnects because of their light weight, non-emissivity, acceptable loss/kilometer, and bandwidth.

Exterior communications is a more difficult matter. Here the conflict is between adequate capability, anti-jam, alternate routes, etc., on one hand, and avoiding distinctive physical or electromagnetic telltales which the enemy could exploit. The following approaches should be considered:

- a. Use a separate communication van linked by line to the C³ van. There should be standby, dispersed, dormant communication vans to which one could switch if the first is destroyed.
- b. Use of airborne relays to provide better screened paths to recipient forces in the face of enemy jamming.
- c. Use of enemy frequencies for high priority transmission (the "sanctuary" approach).
- d. Use of phased array antennas to provide multiple, simultaneous transmissions, low sidelobes, and adaptive nulling.
- e. Use of satellite systems incorporating anti-jam capabilities.

5. Auxiliary Power and Necessary Environmental Equipment

The vans should be equipped for independent operation with necessary power and environmental equipment. Careful selection of the C³ equipment can minimize the power and environmental demands. Protection against nuclear, chemical, gas, and small arms should be provided to the extent mobility considerations permit. In addition, electromagnetic and IR radiation should be suppressed to avoid detection.

6. Built-In Test and Training

The proposed independent operation of these vans places a high premium on reliable equipment, self-check capability, and appropriate spares provisioning. The basic minicomputer(s) must be sized to provide the testing function. In addition, built-in training scenarios should be provided to permit the operators to maintain their skills on their prime functions and to exercise them on changes which might be necessitated by the loss of other vans. To make the training "real-world" it must be done with full recognition of EW factors.

CONCLUSION

I hope the case for survivable C³ is clear. The proposed baseline mobile C³ concept requires and, I believe, deserves detailed design effort. It can provide a common approach which all NATO forces could use, all nations could build, and all could afford. We cannot afford the present situation which is an invitation to PACT adventurism.

AIRBORNE DATA TRANSFER SYSTEM (ADTS)

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ABSTRACT

With the advent of more sophisticated weaponry systems onboard Army aircraft and the projected deployment, by hostile powers, of high speed detection and retaliation equipments, a need for a fast and reliable data handling system is required. To this end, the US Army Avionics R&D Activity, Aviation Research and Development Command, has embarked on a pioneering investigation and hardware feasibility development effort to demonstrate with the user an inter-aircraft and aircraft to ground data handling system which will be capable of transmitting/receiving tactical data employing data enhancement techniques to improve reliability in a Nap-of-the-Earth (NOE) operational environment. The control section of the ADTS, although confined to one black box, is broken into two functional control areas: control of communications Transmit/Receive Controller Module (TRCM) and control of data gathering from onboard subsystems System Controller Module (SCM). The interface ports of the SCM and the TRCM can be configured to match the protocol and hardware requirements of any onboard candidate system. The ADTS also incorporates a data and control input keyboard for operator intervention and an alpha-numeric/graphical display to provide visual data output in the form of text, prompting messages, course information, and display of spacial relationships between aircraft and targets. In a typical application, data, such as target coordinates and aircraft status and location etc. would be transferred between scout aircraft and attack aircraft or ground observer and aircraft. Data handling would be performed in a semi-asynchronous manner employing a realtime designated control system but at the same time allowing any aircraft to access any other aircraft without control system intervention. A scheme is provided to allow source to destination addressing, however, all systems on the same network would receive, for data base update purposes, data being passed between any two data systems.

1. BACKGROUND

In past conflicts involving scout and gunship scenarios, a great deal of difficulty was experienced in detection of targets by scout aircraft and transfer of target location to gunships (FIG 1-1). One method of operation was for the scout aircraft to drop smoke to mark a particular target for the gunship. Obviously problems such as wind velocity and direction which are uncontrollable developed. In addition, the enemy also knew they were being identified. Another method of operation was to verbally communicate target information via the aircraft radios. The scout commander would indicate "there is a target near the crossing" or "by that clearing," etc. The gunship would then have to try and find the target after making sure of the verbal transmission. There were many times when the verbal transmission had to be repeated several times (FIG 1-2). He had time to fly at altitude and search for the target. In future conflicts, the luxury of repeating messages and flying at altitude will no longer be available because of hostile high speed detection and retaliation capabilities. A third method that was employed in the past was to have the gunship remain at a staging area (FIG 1-3). The scout aircraft would then locate a target and fly back to the staging area and lead the gunship back to the target site. Again this results in excessive aircraft exposure time which will not be permissible in future engagements.

FIG 1-4. The critical issues in any future combat engagement will be to minimize aircraft exposure time and to minimize communication time. The first issue will be resolved by flying Nap-of-the-Earth (NOE) taking advantage of surrounding terrain such as masking of the aircraft by a tree line. The gunship must receive precise coordinates of a target (in UTM) from the scout. This means more sophisticated navigation and weaponry systems onboard each aircraft. The gunship will then fly NOE to the target coordinate, pop-up and fire. There will no longer be any time for hovering at 1000 feet while searching for the target. An exposure exceeding a brief interval of time could mean disaster.

The second issue of minimizing communication time will be accomplished by using a fast and highly reliable transmission approach. To reduce probability of intercept by hostile forces, a brief data transmission burst must be used to reduce communication time. The use of error detection and correction coding will enable a high reliability of successfully transmitting a message. Using digital data rather than analog voice will also allow an effective signal to noise enhancement.

2. OBJECTIVE (FIG 2-1)

The objective of the Airborne Data Transfer System program is to develop an advanced technology base (that is, subsystem architecture, interfaces, trade-offs, hardware design, feasibility testing) for a data information handling, handoff and transfer subsystem for application to future Army aircraft systems. The first application would be for a scout-gunship target handoff scenario. The target would be identified by a scout aircraft and the target coordinates, in digital UTM format, would be transmitted via aircraft radios to a gunship. The scout would either have a computer which assimilates information from the Doppler Navigation System and Target Acquisition and Designation System (TADS) and computes the UTM target coordinates. Or the Data Transfer System may have to take the direct inputs from the Doppler and TADS and compute the UTM coordinates itself.

The Data Transfer System would then incorporate some error detection and correction coding to assure high reliability of sending a message to reduce the probability of intercept by hostile forces.

3. WHAT IS ADTS?

The Airborne Data Transfer System (ADTS) program is a structured effort with the user community to develop an advanced technology base for inter-aircraft and aircraft to ground data handling. The system will be capable of transmitting/receiving tactical data employing data enhancement techniques to improve reliability in a Nap-of-the-Earth (NOE) operational environment. The ADTS will be a flexible system whose parameters can be modified per user preferences or per operational (testing) experience. Basically, the ADTS will consist of a control section, a crew input keyboard (CIK), and a display. The control section is broken into two (2) functional areas: control of communications and control of data gathering from onboard subsystems. The data and control input keyboard and display are for test and demonstration purposes. In a future application, existing aircraft keyboards and displays will be used if at all possible. The keyboard is for operator intervention (what type of target, destination of message, etc.) and the alpha-numeric graphical display provides visual data output in the form of text, prompting messages, course information, and display of spacial relationships between aircraft and targets.

Various functions to be evaluated using the ADTS feasibility models are data rates, formatting, coding and information selection. The user community will be queried as to what types of information would be transmitted in various aircraft scenarios. There will be a capability of having the Commander's (scout) ADTS automatically assigning a particular gunship for a particular target based on information received from each gunship as to position location, status, weapon capacity, fuel status, etc. It could have a preprogrammed scenario which selects the first available gunship or the nearest available gunship, etc. This automatic mode could be overridden by the crew (manual intervention). Polling of the status of various aircraft could be done manually or automatically.

In addition, if a scout observed a target and had to maintain complete silence, he could go back to the staging area to give the information to a gunship. He could also give him check point information to enable the gunship to fly to the target area using terrain masking following the path used by the scout. The display would present such check point information. The display itself will be evaluated to determine whether alpha-numeric and graphical capability is necessary or desirable. Perhaps the need for only alpha-numeric capability will result from the ADTS testing phase.

Also to be investigated is the use of various aircraft radios for target handoff application. The VHF-FM is the tactical radio, however, it might be feasible to use either the VHF-AM or the UHF-AM. The flexibility will be there for transmitting on a NOE radio whether it be HF or a high power FM. This would be most useful since Line-of-Sight FM/AM radios will not be ideal in an NOE environment.

The ADTS will have interchangeable ports so that by merely changing cable and interface card/module, a different subsystem can be interfaced. Auxilliary ports will also be available for any future subsystems.

4. HARDWARE CONFIGURATION

In order to meet present and anticipated future Army requirements it was determined that a flexible system architecture was needed. Because future aircraft subsystems cannot be completely projected, a means of interface to many onboard subsystems must be available which require minimal impact on ADTS hardware and firmware. The following architecture was chosen which will meet the stated flexibility requirements. FIG 4-1 is a basic system architecture diagram of the ADTS as it is envisioned onboard an attack helicopter. The ADTS processor system is separated into two functionally separate processing modules, the system controller module (SCM) and the transmit/receive controller module (TRCM). The SCM is the main processing section of the ADTS in that all routine decision making algorithms for pilot unloading reside in the SCM. The SCM coordinates onboard subsystem data and prepares it for transmission. In the case of the attack helicopter this data may come from the crew input keyboard (CIK) and the fire control computer. In aircraft not containing a fire control number (i.e., a scout aircraft) this same data would come from the CIK, the light-weight Doppler Navigation System (LDNS) and Target Acquisition and Designation System (TADS).

The data received from these various subsystems would include target coordinates, aircraft position, target priority, target identity and aircraft status. To this data prestored aircraft source identification and destination identification would be added to form a transmission data package. In the case of the scout aircraft, aircraft destination identification can be added automatically to the transmission package from internally stored data regarding available attack aircraft (see Section 6 regarding Typical Scenarios). The ability of the SCM to automatically assign target information to an available attack aircraft results in reduced pilot workload. It should be noted, however, that all automatic functions of the SCM can be overridden by the pilot. The transmission data package is then passed to the TRCM.

The TRCM is responsible for all operations regarding the transmission of data through the presently available onboard radio links. The TRCM obtains from the transmission data package the destination to which the data is to be sent. The ADTS is capable of transmitting to systems which incorporate a different data protocol than the protocol utilized by the ADTS. When the Army standard data protocol is implemented the ADTS can easily be reprogrammed to conform to the standard format. Therefore, from the destination information the TRCM determines the appropriate data protocol and coding format to convert the transmission data package. In addition, the TRCM selects the appropriate data rate, between 37.5 and 19.2K bits per second, and the radio subsystem. After transmission the TRCM waits for an acknowledgement. If no acknowledgement is received after a predetermined time, the TRCM will repeat the message for a preset number of times. If no acknowledgement is received, the TRCM advises the SCM of its inability to complete the communications link. The SCM in turn advises the pilot via the display system.

FIG 4-2 embodies a more detailed schematic of the ADTS processor system. Both the SCM and the TRCM contain a separate input/output processor as well as processor augmentation hardware.

The SCM I/O processor is responsible for matching the bus protocol of any system, up to eight, interfaced through one of the eight ports. The internal I/O bus structure allows any interface card to be interchanged into any other SCM I/O port and, with the appropriate external cable interchange, maintain interface operation. The SCM can address up to 64 devices with 8 control functions per device. This permits different control scenarios to be resident in the SCM processor to accommodate all envisioned aircraft configurations. In this manner the SCM can determine its subsystem complement. This interface structure permits the SCM to interface with most any system matching that system's protocol with a minimum of impact on ADTS hardware and firmware. To interface to a given subsystem, a single interface card need be designed and the appropriate software handler be implemented (see Reprogramming). Information received from the internal bus N1 is recognized and processed by the SCM I/O processor and passed to the SCM main processor via N2. The SCM main processor contains the decision making algorithms in addition to the subsystem data processing algorithms. The SCM main processor is augmented via the SCM process augmentation module which provides multiply/divide hardware and other augmentations which boost processing speed. The SCM forms the transmission data package and passes this information to the TRCM via bus N4.

The TRCM main processor contains the algorithms necessary to identify the destination and select the appropriate data protocol and code. The TRCM also contains the programming for data rate selection and automatic acknowledge response detection. Once a code has been selected (i.e., ADTS code, TACFIRE code) the TRCM process augmentation module codes the transmission data package. The transmission data package is then passed to the TRCM I/O processor for transmission over the selected radio link.

The TRCM I/O processor contains the necessary data buffers and programmable modem for data transmission. The TRCM I/O processor selects the appropriate onboard subsystem via bus N7 and transmits the data over the same bus. The TRCM main processor, in conjunction with the TRCM I/O processor, constantly monitors the radio system for incoming data. If a signal is determined to be data, the TRCM I/O processor squelches that information from the pilot. Before a transmission is initiated the TRCM main processor determines whether the selected radio is in use by the pilot. If the pilot is using the radio, the TRCM suspends its transmission until that radio link is clear.

It is not the primary intention of the ADTS program to develop a display system and crew input keyboard. However, to evaluate the ADTS various display formats (to include alpha-numeric and graphics), an off-the-shelf display system was selected. A multi-legend programmable keyboard was designed to provide user input to the ADTS as well as test various keyboard function configurations. Display and keyboard requirements developed from this program will be available for incorporation into the specification of a common aircraft display and keyboard. The display and keyboard specification are discussed below.

FIG 4-3 provides a front view of the candidate display. The dimensions of the display are: height: 3.8 inches; width: 4.7 inches providing a usable viewing area of 17.5 square inches. To provide display graphics and alpha-numerics, an off-the-shelf graphic processor translator was selected which is compatible with the selected display. The graphics processor provides up to 2048 vectors or alpha-numerics. The addressable resolution of the display system is 1000 x 1000 points. The graphics processor is of the random scan type with internal display refresh. The alpha-numerics are stored within a ROM contained in the graphics processor. The graphics processor can provide independent fields of information, up to 32, to permit selected field modification or erase.

FIG 4-4 provides a front view of the candidate keyboard. The dimensions of the keyboard are: height: 6 inches; width: 4 inches. The keyboard is arranged in a matrix of 4 x 4 modules. Each module contains two lines of four characters each (upper two thirds of module) and a momentary contact switch (lower one third of module). This arrangement permits the user to press a given switch without covering the display but still provides a low perception error, of display to switch relationship.

The eight character alpha-numeric LED display arranged in two lines provides a completely flexible means of labeling a given switch function. This display method also permits multi-level switch function indication and operation.

ADTS Reprogramming

The flexibility of the ADTS is embodied in its ability to be reprogrammed for most any data handling and transmission application onboard an aircraft. In order not to compromise the flexibility of the system by long lead time reprogramming requirements, a means of reprogramming the ADTS in-house has been devised utilizing an existing mini-computer facility. The existing mini-computer will have resident in it a cross assembler program to convert ADTS source to ADTS object. The mini-computer will have a loader verifier program to program PROMs with the ADTS object code. The mini-computer facility consists of a 16 bit 32K mini-computer, alpha-numeric/graphical display, 2.4M word disk and 600 LPM lineprinter. In addition, the mini-computer has a powerful editor and other support software to facilitate reprogramming. All ADTS programs will reside as disk files on the mini-computer for rapid recall and modification. (FIG 4-5)

In field use maintenance will include replacing PROM cards. At depot level equipments will be available to transfer digital tape master contents to PROM reprogrammers. Preparation of digital tape masters will be performed on the above described mini-computer facility by the R&D Support Command. Mass reprogramming requirement will be served by the R&D Support Command supplying a digital tape master to a contractor for mask programmed ROM's.

5. OTHER APPLICATIONS

In addition to the Target Handoff application between scout and gunship aircraft, other possible applications of data transfer for the ADTS are conceivable. One such application is the MEDEVAC mission using UH-1 or UTAS aircraft. On route to the hospital or medical facility, it is conceivable that data on the patient(s) condition could be forwarded ahead. Advice on how to handle the patient enroute or what to do for the patient could be received from the hospital/medical facility. Short digital messages could be the source of information in each direction. In fact some preprogrammed (canned) messages could be stored. Some medical devices such as an EKG could be one of the subsystem inputs to the ADTS.

Another possible application could be in a NATO type environment. Communications between various NATO pilots/crews could be achieved by having preprogrammed (canned) messages in various languages aboard an American aircraft, a German aircraft, a French aircraft, etc. so that by selecting message number three (3), the German or French crew would generate to the canned message in their own language.

In future applications, an In Operation System Performance Monitor function could be incorporated wherein various aircraft subsystems interfacing with the ADTS could be monitored and an alert message flashed on the display when a malfunction or hazardous situation develops such as loss of oil pressure or low fuel quantity, etc. This can be done if instruments have a digitized output to the ADTS. A Lightweight Doppler Navigation System (LDNS) has its own self test or built-in test feature which signals a fault. This signal could be tied into the ADTS which would alert the crew via the display.

Another application could be the incorporation of various terrain profiles in the ADTS memory. This could be useful for a pilot, unfamiliar with the territory, to make an approach and landing. The terrain profile could be projected on the display to assist the pilot.

6. TYPICAL SCENARIO

The following discourse will concern the ADTS as applied to a typical attack scenario. It should be noted, however, that the tactical position presented here is hypothetical and is used only to illustrate the capabilities of the ADTS and do not necessarily represent approved tactical maneuvers of the US Army.

An Attack Team, comprising four (4) attack aircraft and two (2) scout aircraft, is located in LAGGER area. Prior to take off the aircraft operators initialize their respective ADTS's and perform the system GO/NO-GO tests using the Built-In Test Equipment (BITE). The test results are maintained in the form of status information in the ADTS for periodic maintenance diagnostics. Lead scout aircraft polls all aircraft to set initial aircraft status and position. As all aircraft receive the response to the scout aircraft poll, their respective ADTS's are correspondingly updated. The In Operation System / Performance Monitor routine (IOSPM) is initiated to continually monitor the hardware status of the respective aircraft subsystems alerting the operator of any system failures.

After take off the attack aircraft confirms communication links and proceeds to holding position B. Similarly the scout aircraft confirms communication links and proceeds on target search mission. The scouts are guided by preliminary reconnaissance data stored in their respective ADTS's and presented as heading and distance information which is updated as the ADTS samples data from the onboard navigation systems. (FIG 6-1)

Scout aircraft SH2 proceeds to position C in NOE flight. At position C SH2 unmask, sights and designates targets with Target Acquisition System. The onboard ADTS samples the coordinate output of the targeting system and requests target priority and target I.D. from operator. SH2 remask and the operator complies with the ADTS request. The ADTS displays the second target concentration heading and distance information and SH2 proceeds directly to the position as it is near his present location.

SH1 has reached position D, the target concentration of potential targets. SH1 unmask and acquires several targets with the onboard target acquisition device. After remasking, the operator complies with the requests of the ADTS to enter the target priorities and identifications of all the targets previously designated and stored automatically by the ADTS. SH1 proceeds to position B to disseminate the information to the available attack aircraft. (FIG 6-2)

While SH1 is enroute to position B, SH2 has arrived at position E, designated the targets at that location, entered the request information into the ADTS and proceeded to holding position F. The operator of SH2 has opted to indirectly direct the attack aircraft to the various stored targets. The operator of SH2 initiates indirect target direction mode (ITDM) of the ADTS and is presented with a display graphically indicating the locations of the targets, the present position of SH2 and the route SH2 took from the LAGGER area to position F. With this information, the SH2 operator can enter on the ADTS display the most direct and safest course for the attack aircraft to follow to find the targets. The procedure takes less than a minute. SH2 initiates an update transmission request to position B polling all attack aircraft to determine their position and status. The poll reveals that all aircraft are available. The ADTS automatically makes target assignments to the first two aircraft. The ADTS then automatically transmits the information concerning the targets (i.e., location, priority, identification) and the necessary course information to the respective attack aircraft. The total time for all transmissions will be less than 10 seconds.

AH1 and AH2 immediately proceed to their respective targets and SH2 is free to locate other potential targets. (FIG 6-3)

SH1 has arrived at position B to directly disseminate its target information to the remaining attack aircraft. As SH1 proceeded from position D to position B the ADTS has sampled the onboard navigation system storing checkpoint information. When SH1 arrives at position B, the target information is passed to the attack aircraft along with the checkpoint information which is interpreted by the attack aircraft ADTS and presented as heading information in reverse order to the attack aircraft operator. AH3 and AH4 proceed, following the course information, to their respective targets. (FIG 6-4)

This hypothetical scenario demonstrates two possible means of disseminating target information from scout aircraft to attack aircraft utilizing the ADTS. The first method as utilized by SH1, is the direct target direction mode (DTDM). This mode required SH1 to fly back to the attack aircraft staging area (position B). SH1 then transmitted the target information along with the return course information sampled by the ADTS from the navigation system. The second method, the indirect target direction mode, while retaining the capability of passing target course following information, did not require SH2 to fly back to position B. Instead the SH2 commander moved to a point of relative safety, entered the course information utilizing the graphics display and keyboard, and then transmitted this information to the attack aircraft. Had the transmission link been poor SH2 could have gained altitude briefly and initiated the

short (10 second) transmission. This mode of operation would not be feasible utilizing conventional voice transmission means. (FIG 6-5)

7. COMPUTER SIMULATION

When new systems are introduced, it is frequently difficult to determine many of the design parameters in advance of the hardware. For the purposes of writing a statement of work (SOW) and in order to better evaluate proposals, preliminary versions of ADTS segments were simulated utilizing an existing interactive graphics mini-computer system (see FIG 4-5). By utilizing the graphics of the mini-computer system an evaluation of information could be made to determine what types of data would best be presented graphically (FIG 7-1). In order to size the proposed ADTS in regard to processor speed and memory capacity, typical ADTS control scenarios were programmed into the mini-computer system. Linking the software which controlled the alpha-numeric/graphical information with the ADTS control scenarios yielded a system which could simulate the ADTS. Expanding this approach, three autonomous ADTS control scenarios, two simulating attack aircraft and one simulating a scout aircraft, were implemented in the mini-computer system in a multi-tasking operation. With this approach the operator can take the part of the crew of either aircraft and interact with the remaining two aircraft simulating a search and destroy mission. Because each aircraft control scenario is a totally separate program running concurrently with the other programs, any one can be altered or modified without affecting the remaining programs. A means was developed to simulate the transmission of data between aircraft (control scenarios). As in real system operation a transmission directed to one aircraft is received by all aircraft, so it is with the computer simulation of the three ADTS's. If, for example, the scout aircraft initiates a transmission to AH1, AH2 also receives the information, however, only AH1 responds because the AH1 scenario obtains the correct destination code match. AH2 also scans the destination code and does not match, however, AH2 does store the information obtained for update purposes.

Utilizing the mini-computer in this manner provides a means of experimenting with possible control scenarios before any hardware is received for testing. This approach will also shorten the experimentation required using the actual ADTS hardware. Information and scenario flow diagrams derived from the mini-computer system can be directly implemented on the ADTS when it becomes available.

As the ADTS hardware design becomes further defined the mini-computer simulation will be modified to provide a more accurate representation of the actual system. With the actual configuration of the display and keyboard determined, the simulation is now being modified to present the information exactly as it would appear on those devices.

This paper is intended as an introduction to the ADTS program. Subsequent papers will be offered detailing the ADTS hardware when it becomes available and the results of the ADTS testing program.

BACKGROUND:

DIFFICULTY EXPERIENCED IN HANDING OFF TARGET
LOCATION INFORMATION DURING PAST CONFLICTS

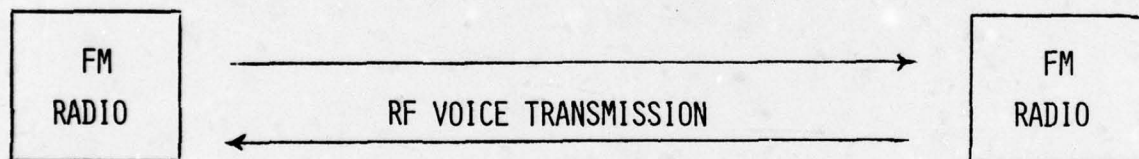
- * - DROPPED SMOKE TO LOCATE TROOPS
- * - COULD NOT GET GUNSHIP PILOTS TO UNDERSTAND TARGET
LOCATION - HAD TO SEARCH FOR TARGET
- SCOUTS FLEW BACK TO STAGING AREA AND LEAD COBRAS
TO TARGET SITE

Figure 1-1

EXISTING TARGET HANDOFF COMMUNICATION SYSTEM

SCOUT AIRCRAFT

GUNSHIP AIRCRAFT



- CHANCE OF ERROR IN TRANSMITTING TARGET COORDINATES
- CHANCE OF HAVING TO REPEAT MESSAGE SEVERAL TIMES
- CHANCE OF BEING INTERCEPTED BY ENEMY

Figure 1-2

BACKGROUND: DIFFICULTY EXPERIENCED IN HANDING OFF TARGET LOCATION
INFORMATION DURING PAST CONFLICTS

- DROPPED SMOKE TO LOCATE TROOPS
- COULD NOT GET GUNSHIP PILOTS TO UNDERSTAND TARGET
LOCATION - HAD TO SEARCH FOR TARGET
- * - SCOUTS FLEW BACK TO STAGING AREA AND LEAD COBRAS
TO TARGET SITE

Figure 1-3

CRITICAL ISSUES

MINIMIZE AIRCRAFT EXPOSURE TIME

MINIMIZE COMMUNICATION TIME

Figure 1-4

AIRBORNE DATA TRANSFER SYSTEM

OBJECTIVE: DEVELOP AN ADVANCED TECHNOLOGY BASE (I.E., SUBSYSTEM ARCHITECTURE, INTERFACES, TRADEOFFS, HARDWARE DESIGN, FEASIBILITY TESTING) FOR A DATA INFORMATION HANDLING, HANDOFF, AND TRANSFER SUBSYSTEM FOR APPLICATION TO FUTURE ARMY AIRCRAFT SYSTEM.

Figure 2-1

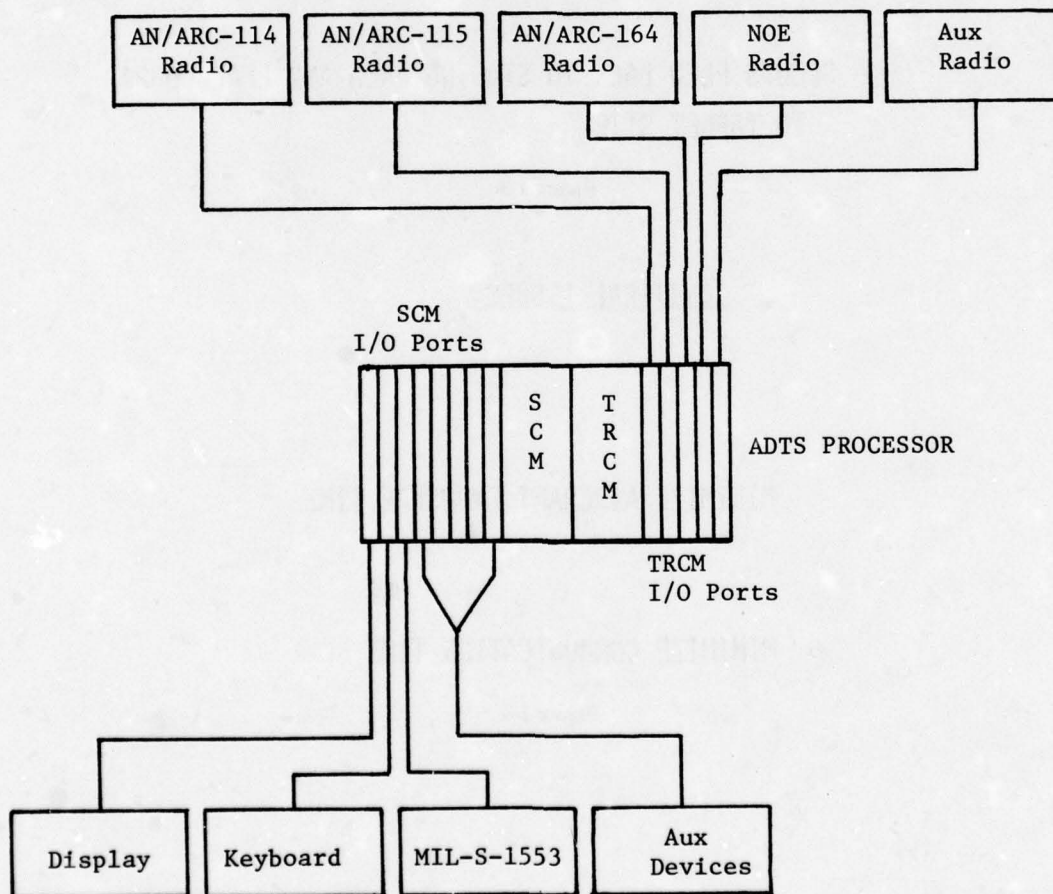


Fig.4-1 ADTS architecture

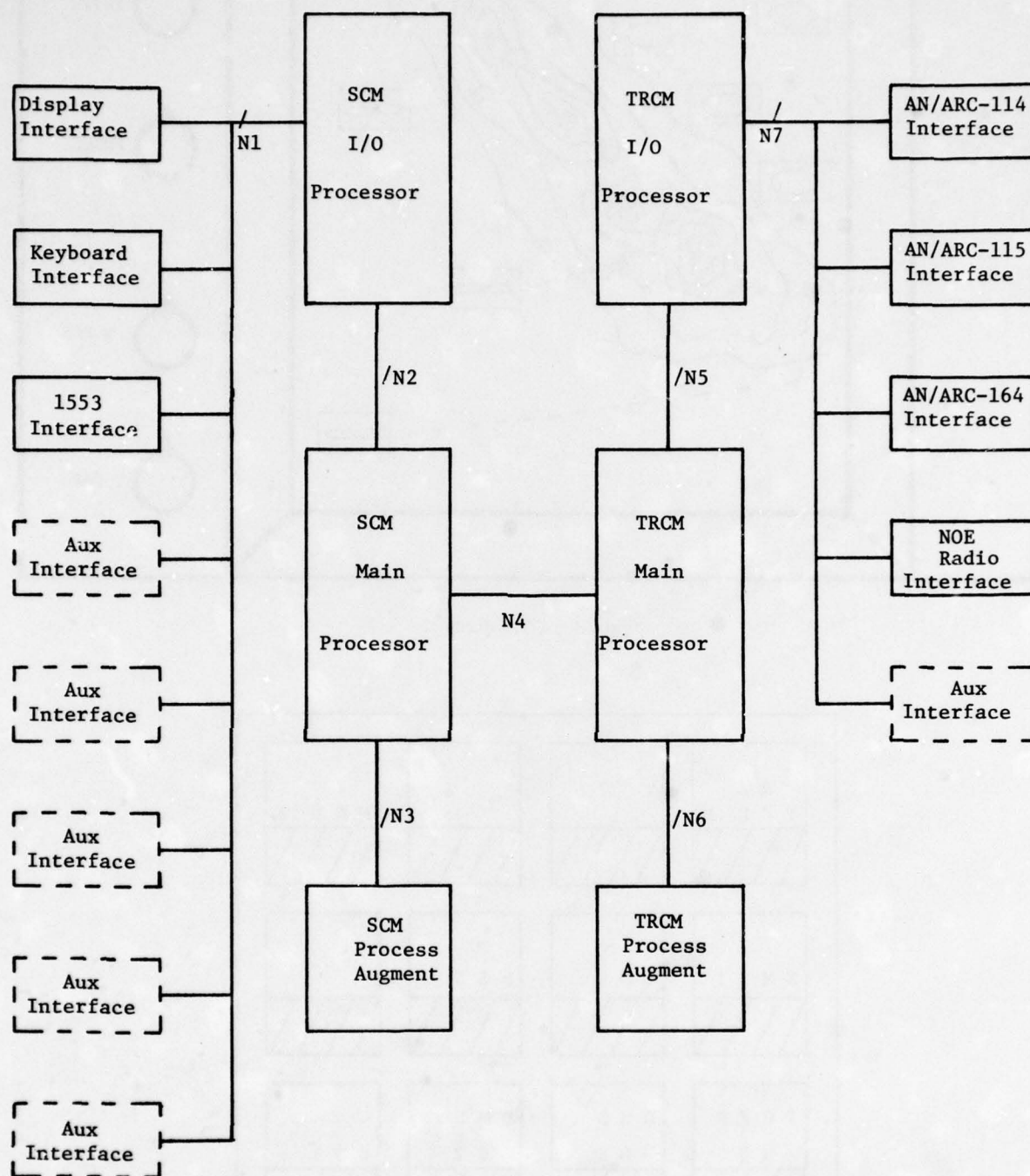


Fig.4-2 ADTS process system architecture

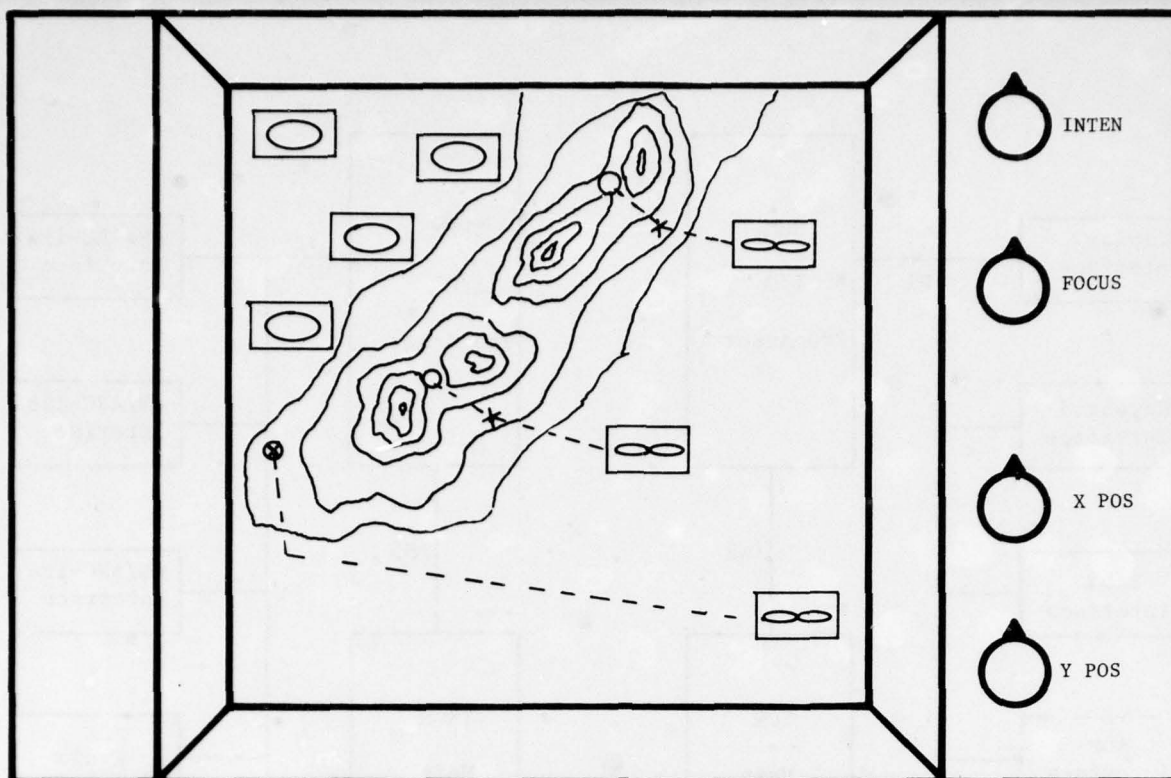


Fig. 4-3 ADTS display

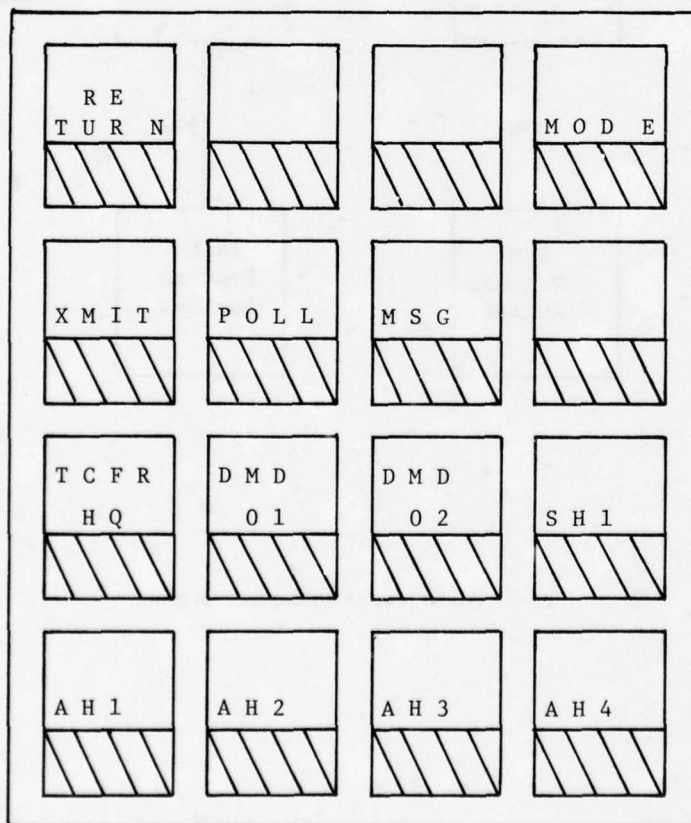


Fig. 4-4 ADTS keyboard – scout message initiation mode



Fig.4-5 ADTS simulation and reprogramming facility

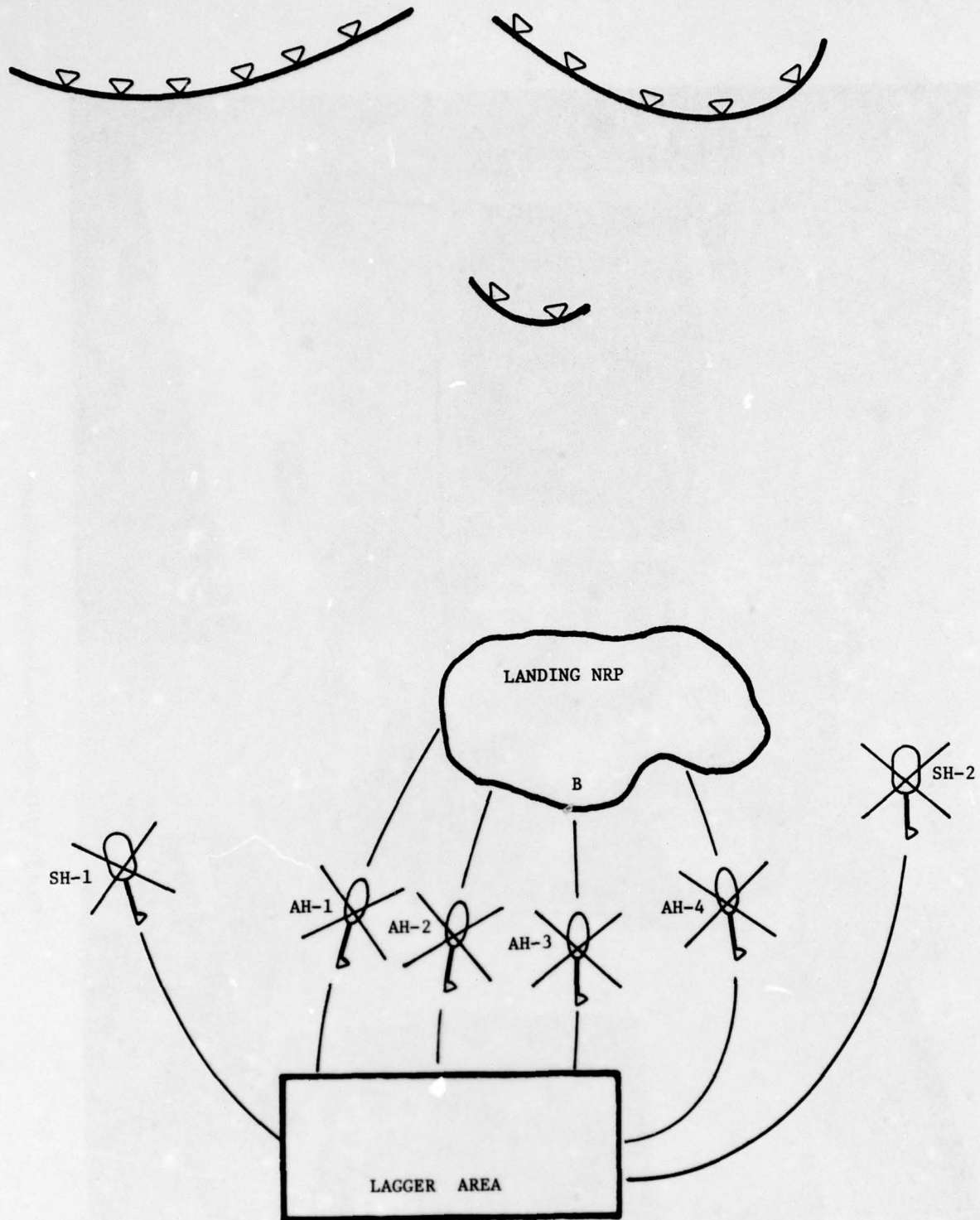


Fig.6-1 Tactical scenario

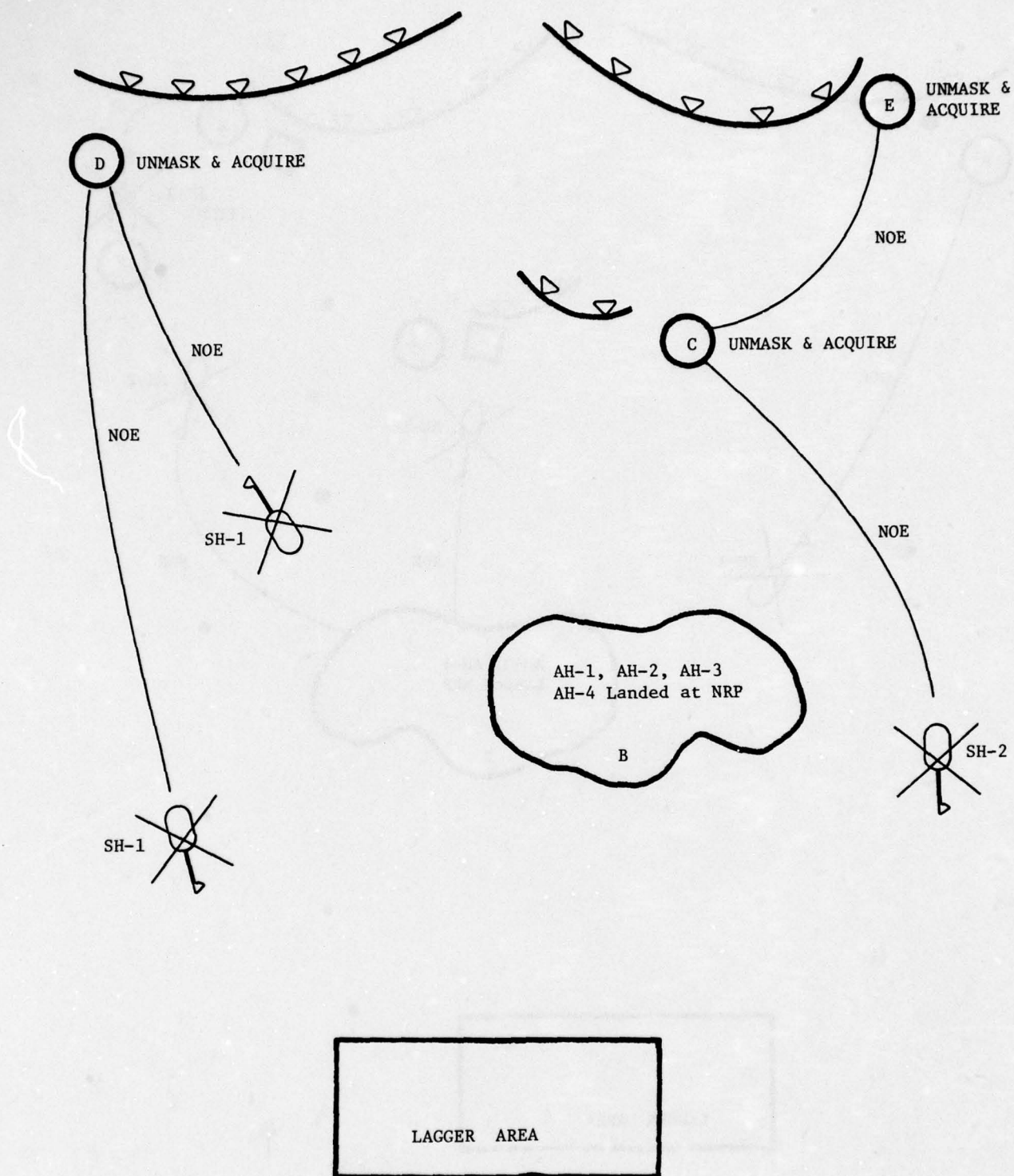


Fig.6-2 Tactical scenario

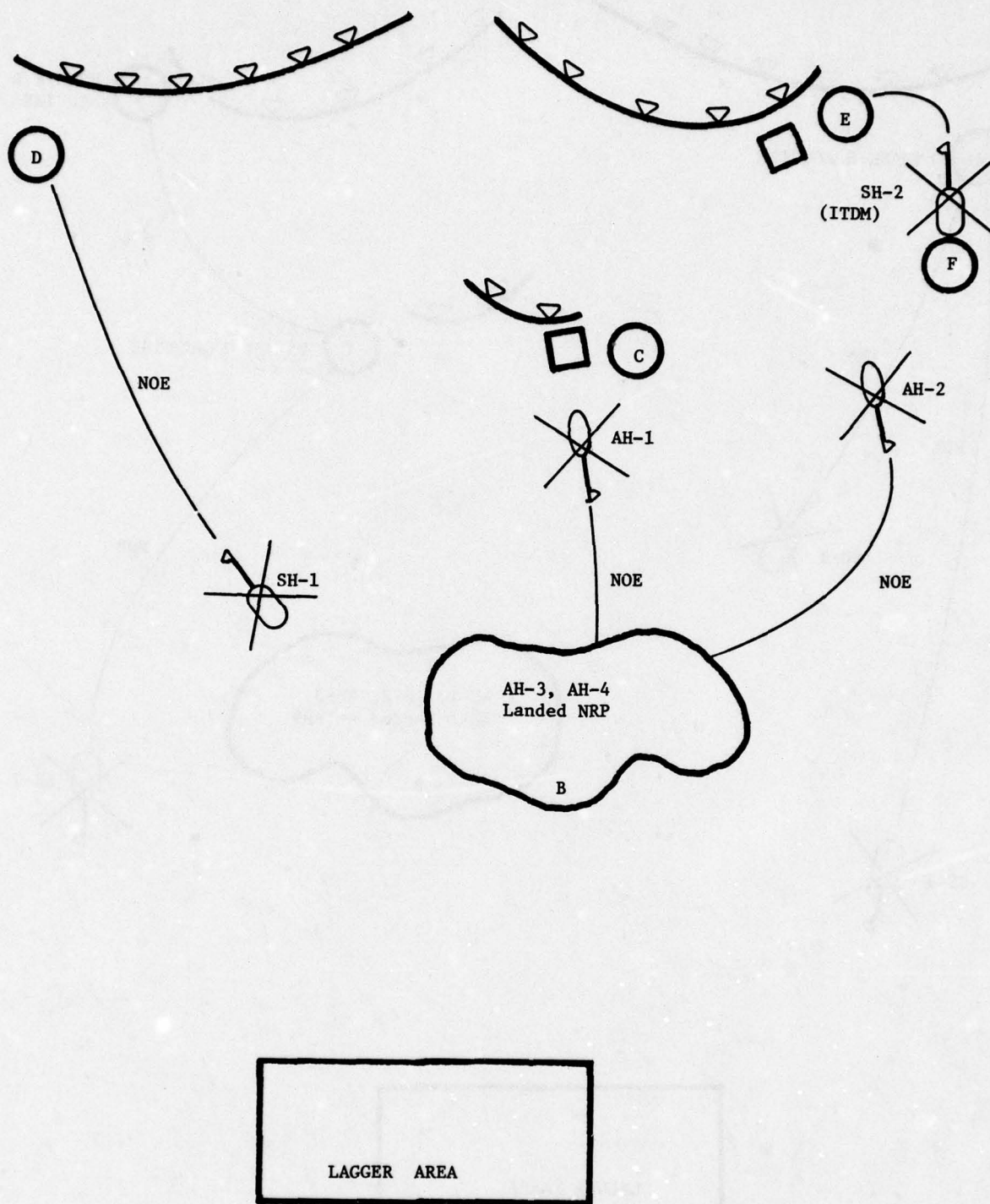


Fig.6-3 Tactical scenario

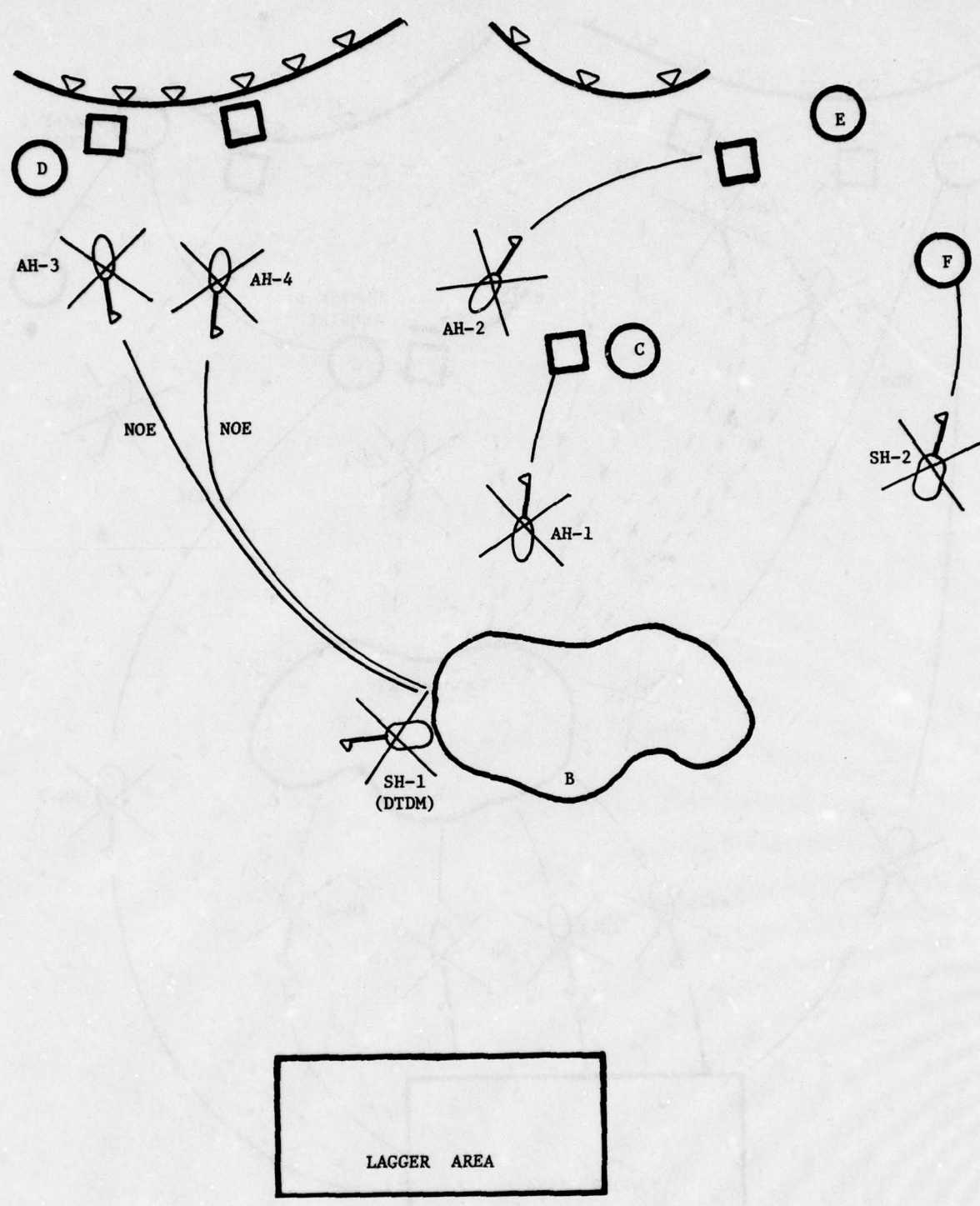


Fig.6-4 Tactical scenario

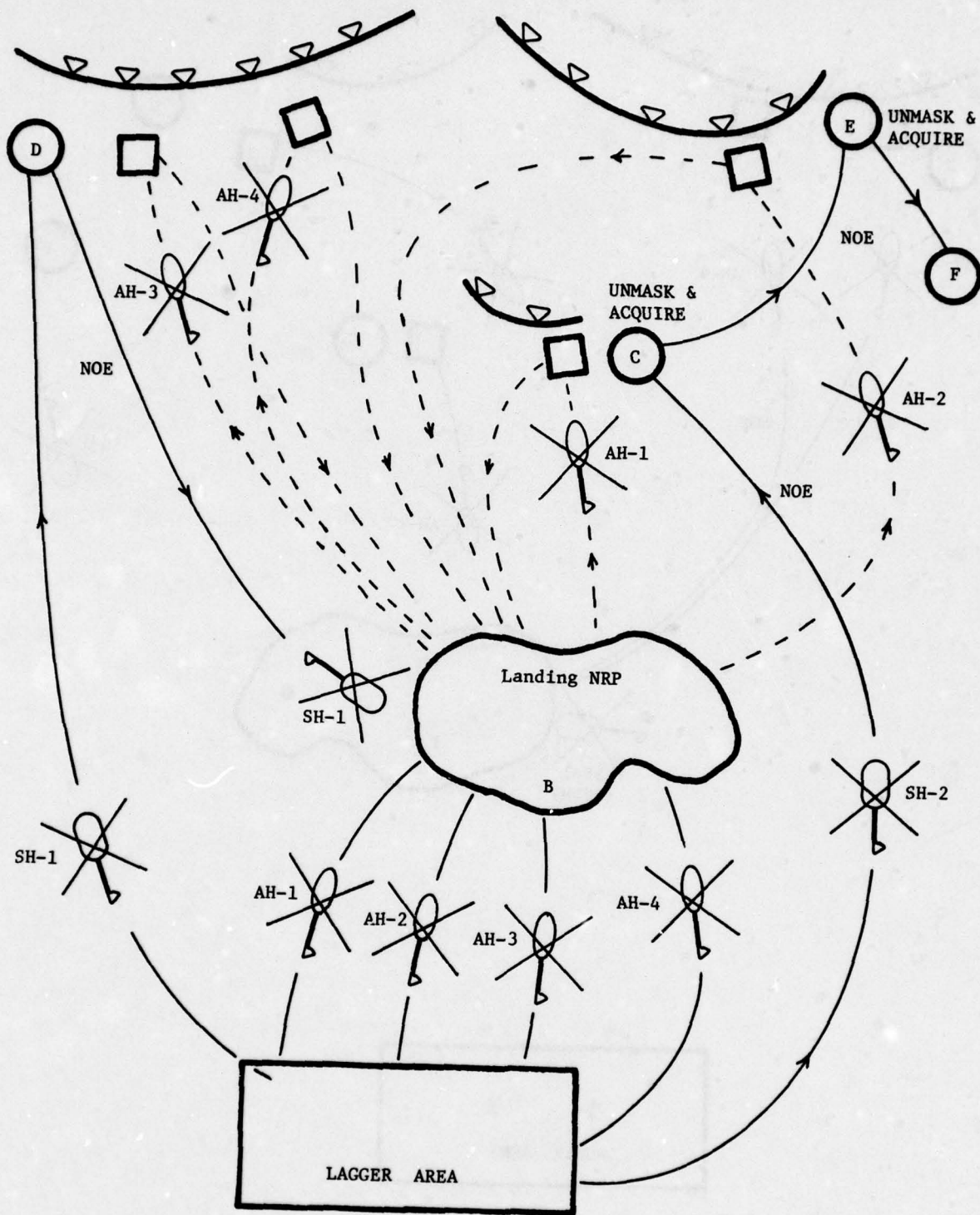


Fig.6-5 Composite tactical scenario

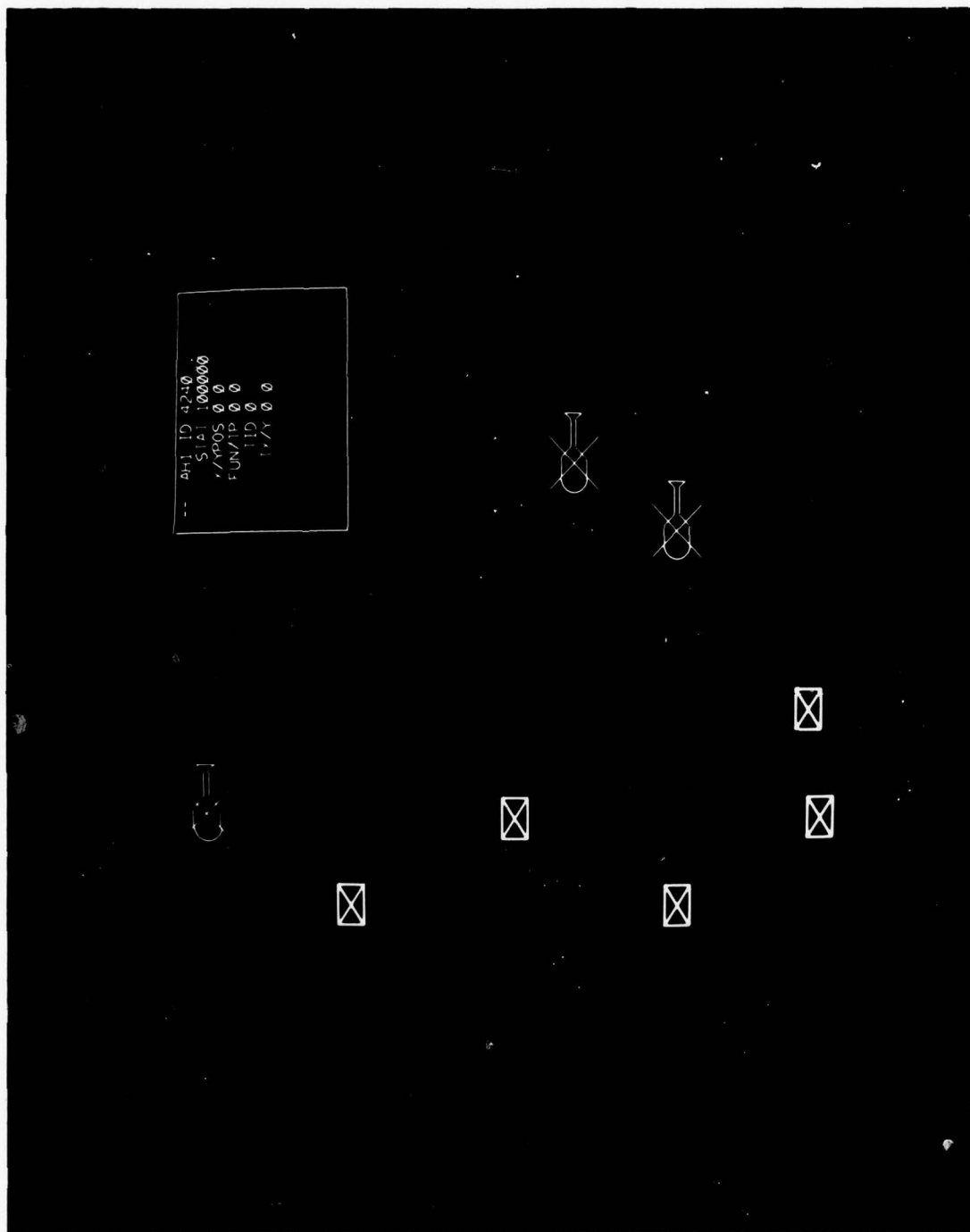


Fig. 7-1 ADTS display simulation

PRECISION LOCATION STRIKE SYSTEM

NEAR-REAL-TIME

C³I FOR THE TACTICAL BATTLEFIELD

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SUMMARY

The Precision Location Strike System (PLSS) will provide the battlefield commander with an all-weather, near-real-time, integrated target location and strike capability. To achieve near-real-time communications, command, control and intelligence (C³I) interface capability, the PLSS is being developed with a Central Processing Communications Element (CPCOM). The CPCOM computer automatically processes emitter location, tasking, and weapon delivery data into formatted messages, which are distributed over appropriate AUTODIN, TADIL-B, teletype and 485L Digital Data Links.

The Air Force and Army C³I organizations in the theater will receive PLSS information which supports near-real-time:

- * tactical control
- * air surveillance and airspace control
- * intelligence/fusion functions

The CPCOM is architected such that the changing theater C³I structures and message standards will have minimal impact on the other PLSS elements and can be easily accommodated by the CPCOM. In addition, the CPCOM will have data transmission filters which can limit the data being distributed on each ground-to-ground data link to that data of importance to the receiver. This filtering scheme will also be used to limit the data transmitted to manual facilities.

The PLSS CPCOM's full capabilities can only be realized when other theater C³I elements provide automated facilities which can close the near-real-time loop. Until that time, the PLSS can still provide valuable information to manual and semi-automated facilities.

1. INTRODUCTION

1.1 Overview

The Precision Location Strike System (PLSS) will provide the tactical battlefield commander with an all-weather, near-real-time, integrated target location and strike system. This capability will revolutionize tactical conventional warfare concepts of operation in the 1980s and beyond by providing the battlefield commander, operations, and intelligence facilities with virtually instantaneous information on battlefield developments. The PLSS system is being developed to operate in the dense electro-magnetic environment expected during the mid-1980s in the European area and with the mobility to deploy to other areas of the world.

1.2 PLSS Elements

The system consists of intercept/relay aircraft, attack aircraft carrying unguided or stand-off guided ordnance, a ground computer facility and ground navigation beacons. All of these elements are connected by data links over which the necessary navigation, location and weapons commands are passed among the PLSS system elements. In addition, input/output of PLSS communication, command, control and intelligence (C³I) data will occur in near-real-time with other battlefield systems.

2. CONCEPT

2.1 Intercept

The PLSS concept involves the detection of enemy electronic emissions by the PLSS intercept/relay aircraft. The detected emissions are pre-processed by the on-board equipment and relayed to the PLSS ground computer facility. Within the computer facility, the precise position of detected emitters is calculated within the PLSS grid system. The detected emitter location data is passed to the communications element for forwarding to other battlefield systems for a decision on attacking the target and for intelligence functions. The PLSS contains software to convert the PLSS grid system to Geodetic (Latitude/Longitude) or Universal Transverse Mercator Coordinate systems.

2.2 Location

The precise location of a PLSS detected target relies on precise location of the PLSS intercept/relay aircraft. The aircraft continuously interrogate ground navigation beacons and relay the distance measuring equipment responses to the computer facility for processing and calculation of precise location of the aircraft. The position of the intercept/relay aircraft provides the basis for determining the position of the emitters

and attack aircraft/weapons.

2.3 Strike

PLSS-associated attack aircraft will carry either conventional stand-off guided weapons or conventional unguided weapons. The attack aircraft will receive guidance commands to a release basket in the case of guided weapons aircraft or to a precise release point for unguided weapons aircraft. Guided weapons commands are relayed through the intercept/relay aircraft after release until weapon impact. In the case of unguided weapons, the PLSS computer facility actually commands the release to obtain the required weapons accuracy.

2.4 Targets

Targets for PLSS attack can be provided by the PLSS emitter location function or can be inserted into the PLSS computer if targets are designated from external sources. The only limitation to external targeting is that the targets must be designated with sufficient accuracy for a PLSS weapon attack to achieve the desired probability of kill.

2.5 Information Distribution

The types of information sent to various battlefield organizations from the PLSS ground computer facility are tactical control and tasking, air surveillance and airspace control, and data to support intelligence/fusion activities. The full utilization of the PLSS capability to provide and receive near-real-time data for tactical applications is directly related to the capability of the interfacing battlefield systems' automated capabilities for processing this data. The handling of this data on the PLSS side of the interface is the topic of this paper. Figure 1 depicts the elements of the PLSS.

3. CENTRAL PROCESSING COMMUNICATIONS ELEMENT (CPCOM)

3.1 Description

The CPCOM is one portion of the PLSS ground computer facility and contains all of the equipment for voice and data communications with the battlefield agencies external to the PLSS system. The CPCOM consists of an AN/UYK-25 computer, interfaces to the navigation and location computers, modems, encryption equipment, wirelines, UHF and HF radios.

Data is passed among battlefield components and PLSS in near-real-time to support tactical control, air surveillance and airspace control, intelligence and fusion. There are various other types of information which are passed infrequently or on a scheduled basis, but due to its non-near-real-time nature, is considered outside of the scope of this paper.

3.2 Interface Definition

The actual CPCOM data interface functions are being examined in terms of nine layers of interface definition:

a. Media Identification

Defines the specific data communications media including the number of paths and options.

b. Media Hardware

Defines the signal level, wave forms, signal duration, interval synchronization, character codes, etc. for each media.

c. Transmission Media Structure

Defines the block sizes, framing control, error detection/correction, etc. for each media.

d. Transmission Media Handling

Defines the content and format of message headings, endings, and communications messages for each media.

e. Information System Handling

Defines the format and ordering of message identity description information, methodology for transmission of data elements and their interrelationships, methodology for relating data elements to the recipients' information system structure and permissible transaction instructions. These procedures are not unique to each media.

f. Information System Message Content

Defines the messages available, including formats, data elements, hierarchy, number of occurrences, order and conditions of use. These procedures are normally, but not necessarily, related to a particular information system and are not related to one media.

g. Data Elements

Defines the data characteristics, codes, meaning and uses of individual data elements found in the message formats identified and controlled in Layer f. They should not be related to one media or information system.

h. Information Conveyance Requirements

Arbitrarily divides a mission into discrete activities and describes the conditions and events requiring transmission of formatted data to specified recipients.

i. Environment

Defines the availability and capability of battlefield entities and the communications media that connect the entities to the PLSS.

Each layer of the interface definition process is necessary for automated data handling. This process is extremely difficult and time-consuming and further complicated by the requirement for PLSS to be capable of operating in any theater. In addition, many of the battlefield systems' data handling techniques, messages, hardware and even the media are not fully defined at this time due to the relatively recent interest in near-real-time data exchange for the tactical battlefield.

3.3 Flexibility

The PLSS CPCOM is structured so that hardware and software changes due to changes in transmission media, protocols, message standards, etc. will not impact the navigation and location computers also within the PLSS ground computer facility complex. This is accomplished by rigorously defining the data elements which are to be passed between the CPCOM and the location and navigation computers. The processing software in the CPCOM is modularized to allow minimum impact when changes are identified. In addition, careful selection of "off-the-shelf" modems and line control function hardware will lessen change impacts to hardware by selecting multiple media line controllers and modems. As the definition of joint US message standard proceeds and eventually merges with NATO requirements, software and hardware changes will be accomplished with minimum impact.

3.4 Data Filtering

A data transmission filtering capability will be incorporated into the CPCOM to assure the receiving battlefield system receives only the information for which it has a near-real-time need. Emitter data will be compared to a table of known emitters and if the emitter has been previously reported, the emitter data will not be sent. In addition, each receiver of PLSS emitter data can specify geographic areas and types of emitters for which he wishes to receive data. The filters for each PLSS output link are updated prior to a mission and may be changed during the mission to reflect changing battlefield interests. This filter capability reduces the output link loading and reduces the amount of data each recipient must handle and/or process. In addition, PLSS will probably be deployed before many of the battlefield systems have automated processing and handling capability for incoming PLSS information. The filter capability will allow these manual or semi-automated facilities to prioritize data needs and receive only the data reflecting their need prioritization.

3.5 Transmission Media

The requirement to communicate in near-real-time with many types of battlefield components in any theater of operation has resulted in four transmission media which have differing protocols, message standards and associated hardware. The transmission media planned for incorporation are AUTODIN, 485L Digital Data Link (DDL), TADIL-B and Teletype. These four media will allow PLSS near-real-time communication with the appropriate battlefield facilities in any conceivable theater of operation. Figure 2 indicates the general messages and media requirements for PLSS near-real-time data communications and Figure 3 shows the general data handling capabilities.

3.6 Problems

There are many problems associated with developing a multi-media data distribution capability. The most significant problem is the evolutionary process of developing message standards. The PLSS CPCOM is being developed to adapt to accepted message standards. However, in several cases, the standards are of an interim nature and change rapidly. It is difficult to adapt rapidly enough to these changing requirements. In addition, in some cases the message standards have not been suitable for passing PLSS data. Requests for changes to fully established message standards can easily take one to two years to resolve and be reflected in the media documentation and hardware.

In addition, the development of unique national data communication capabilities impedes the multi-national information exchange essential for battlefield command and control in the European theater. However, as NATO tactical data communications systems are established, the inherent flexibility of PLSS hardware and software will permit the change-over with minimum impact. A NATO tactical data communications system will have to provide not only the hardware for transmission media, but the message standards to allow automated processing on both sides of the interfaces. In addition, there must be provision for non-automated facilities. The rigorous formatting requirements required for automated

data handling can be a barrier to non-automated data handling due to the human error factor.

4. CONCLUSION

The development of automated data handling systems to provide near-real-time data to the tactical battlefield users requires a systematic interface layer definition process. However, due to the rapid changes in the message standards, media requirements and lack of NATO-wide standards, the flexibility to alter system hardware and software must be possible with minimum system impact. Partitioning of the data communications systems from other automated capabilities and filtering transmission data to reduce the media loading and processing can aid in the system development.

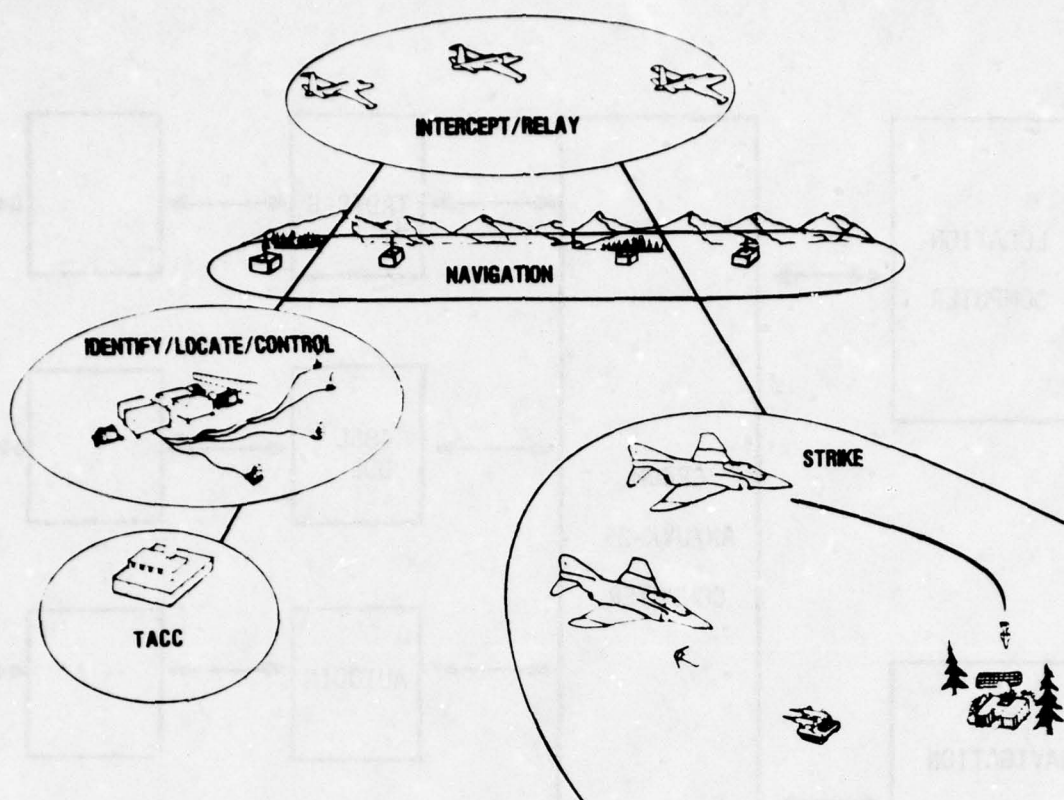


Fig.1 Precision location strike system

		MEDIA			
		TADIL-B	485L DDL	AUTODIN	TELETYPE
I N F O R M A T I O N	AIRCRAFT POSITION REPORTING	X			
	EMITTER REPORTS	X	X	X	X
	IMMEDIATE STRIKE		X	X	X
	WEAPON INFORMATION		X	X	X

Fig.2 PLSS near-real-time data matrix.

Note that not all media will be used in any theater and not all information is required in near-real-time in all system deployment concepts

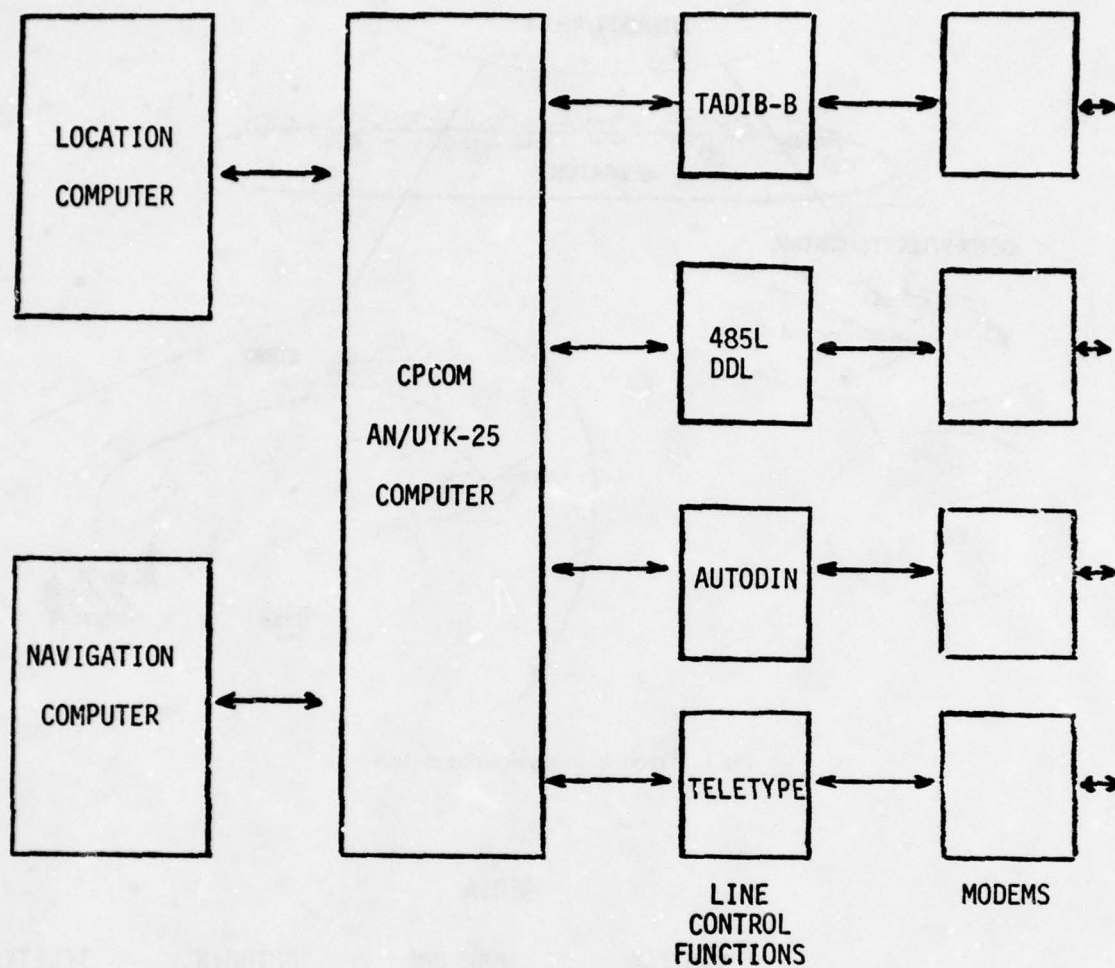


Fig.3 PLSS data handling

MSI-80S

AN INTEGRATED SMALL-CRAFT FIRE CONTROL SYSTEM

by

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SUMMARY

MSI-80S is the name of an Integrated Fire Control System developed for Fast Patrol Boats in the Royal Norwegian Navy. The paper deals with the specific threat, the philosophy behind the operational aspects and the system description of the fire control system. The results given are based upon the technical evaluation of the prototype aboard KNM "HAUK" autumn 1977.

1. INTRODUCTION

The Royal Norwegian Navy (RNON) have a vast experience using Fast Patrol Boats (FPB) since World War II. Based upon this experience and the results from the development of a new fire control system for the RNON submarines, the requirement for the new FPB-class was established in the early seventies. These new FPB's were named HAUK (HAWK)-class.

2. THREAT

The geographical position of Norway is shown on this map. (Fig. 1). Keypoints here are, starting from the north:

- o A border to Russia
- o A long coastline towards the Barents Sea and the North Sea

Adjacent to the Norwegian border is the KOLA peninsula where the Soviet Union has the biggest combined base-system in the world. The icefree distance from the Soviet Union's bases to the Norwegian border is about 100 km.

The Russian Northern Fleet is the Soviet Union's largest maritime force of which their submarines with ballistic missiles represent the biggest threat to the NATO-countries. Most of these submarines operate from the bases in KOLA.

The North Sea is, from a military point of view, of equal importance due to the fact that it is the end point for the reinforcement and supply lines to central Europe; it contains the main routes for NATO reinforcement from Britain to Denmark, and it is essential that NATO has control of this area to prevent the enemy from breaking through into the Atlantic.

In order to secure a free passage for the Russian Northern Fleet from the KOLA bases and the Red Banner Fleet operating in the Baltic, Soviet Union control of Norwegian strategic harbours is of vital interest. Since those areas play such an important role for the Soviet Union and the Warsaw Pact, it is of equal importance to NATO. One of the main tasks of the RNON is therefore to stop an invasion.

The length of Norway to defend is large (about 1100 miles), the coastline with fjords etc. is about 15 times that distance. The coast is scattered with islands, and the water is shallow which puts great demands on knowledge concerning local conditions when operating in these waters.

In a few words the battle area is well suited for hit and run tactics. This is the basic idea of using small fast boats equipped with offensive weapons under the command of a crew drilled to operate in this environment. The success of FPB operations depends heavily on the vessels ability to be at the right place at the right time, and their ability to launch the weapons against the enemy without being detected. This can only be achieved by the right combination of tactics and equipment, where the Weapon Control System plays a major role.

3. PHILOSOPHY BEHIND OPERATIONAL REQUIREMENT

A powerful ECM resistant Fire Control Radar is not only susceptible to early intercept and identification, but is also vulnerable to enemy Electronic Warfare, like for instance use of "chaff" and "decoys".

In order that the FPB can remain undetected, it is required that target detection, identification, and tracking can be achieved by passive means. This led to a sensor concept where the expensive and powerful ECM resistant Fire Control Radar was substituted by a commercial high quality navigation radar with satisfactory accuracy and range, complemented by a set of electro-optical sensors like Low-Light TV (LLTV), Infrared (IR) vision and Laser Range Finder (LRF). These sensors provide considerable ECCM capability, target detection, and passive tracking together with night vision for identification and navigation in narrow waters.

The expenses saved on the Fire Control Radar were sufficient to finance the electro-optical sensors.

The other important consideration was the command and control. The introduction of wire-guided torpedoes and Penguin SSM requires equipment to ensure co-ordinated deployment and target allocation within the FPB divisions. This requires automatic data processing with an adequate number of displays.

This led to the MSI-80S (Multi Sensor Integrated Control System for the 80s Surface). The evaluation model was delivered early 1977, and went through a technical evaluation autumn 1977 aboard the prototype of the "HAUK"-class FPB. The first operational system will be delivered mid summer 1978. Main data for "HAUK" is given in appendix 1.

4. SYSTEM CONFIGURATION

Figure 2 shows the system configuration. The weapons to be controlled are 2 wire guided torpedoes, 6 Penguin Ship to Ship Missiles (SSM), and one 40 mm L70 gun.

The sensors are:

- o The electro-optical system, consisting of a Low-Light-TV-System, a Laser Range Finder and an Infrared vision System.
- o The radar system: Consisting of 2 radars
- o The TV-tracker system, which is an autonomous system designated to the L70 gun.

The data processing distribution and presentation is controlled by a highly integrated 3 operator's console.

- o Tactical Operator
- o Weapon Operator
- o Passive Sensor Operator

The commanding officer's place is in front of the operators console. At this position he will have all the information he needs in one glance. At the same time he maintains quick reaction and control of weapons, together with the position of hostile and friendly units.

The next chapter describes the different subsystems in more detail. Special emphasize is put on handling, integration and presentation of the data. The main specifications of the equipment are given in appendix 2.

5. DESCRIPTION OF SUBSYSTEM

5.1 Radar System.

The data for command, control and weapon delivery is provided from a variety of sensors of which the radar system is the only all weather sensor. The system selected consists of two commercial Decca 1226 navigation radars. The use of one 6 ft and one 9 ft antenna with special interswitching between 3 transceivers gives a high degree of flexibility and provides some ECCM. The 9 ft antenna and its two transceivers are coupled so as to serve as primary radar for MSI-80S while the 6ft antenna and its transceivers are referred to as the navigation radar, though fully integrated in the MSI-80S.

Automatic radar extraction of targets combined with Kalmanfiltered data processing provide required accuracy for the control of the torpedoes and the Penguin missiles with the latter's variable geometric flight-path.

5.2 Electro-optical System.

The original electro-optical sensor concept was based upon the implementation of IR-vision (thermal imagers, FLIR) complemented by a modest LLTV system for passive detection, identification and target tracking during day and night operations. After concluding an extensive market survey it was decided to postpone the integration of IR-vision in this project for the time being. The electro-optical platform is, however, prepared to accept an IR-sensor whenever the Navy finds it cost-effective.

Instead the decision was made to use an ISIT LLTV system which gives required night vision to 10^{-3} lux (starlight capability). Improved camera tubes and automatic iris control greatly reduce the blooming effect of the LLTV system, while retaining a favourable light sensitivity and S/N ratio.

The other elector-optical sensor used is an L.M. Ericsson sea target laser range finder collimated to the LLTV system. By placing the trigger and receiver units in closed environment, a high degree of electronic interference protection has been achieved. Attenuation filters are used to provide peace time training without hazardous risks to implicated personnel.

5.3 Stabilized Platform.

The electro-optical sensors are mounted on a three axis specially designed stabilized platform giving true horizon positioning of the sensors. The stabilizing element is an integral part of the platform, weather protection being achieved by a half dome construction. Signal transfer is by sliprings and the platform is prepared for mounting additional sensors.

In addition to stabilize the E/O-sensors the platform gives data of the roll and pitch movement of the ship to the various users together with the ship attitude data for weapon control. The key elements in the stabilized platform are 2 gyros, 2 accelerometers and a microprocessor. By using a velocity input from a log (accuracy $< 0,5$ knots) the microprocessor also generates own ships data in absolute geographical co-ordinates.

5.4 TV-Tracker System.

The 40 mm L70 is primarily for air defence and will be controlled by an autonomous unit - a TV Tracker. The TV camera head is manually brought into vicinity of the target, after which the TV operator locks on the target by means of his monitor and joystick. The TV tracker then automatically tracks the target and controls the gun's bearing and elevation.

The weapon operator can, however, designate targets to the TV tracker system by means of a special target designation unit which provides the TV tracker system monitor with target range and bearing. Features for automatic slaving of the electro-optical package on the platform to the TV tracker azimuth bearing are also provided.

On the stabilized tracker a small Radar Search Receiver (RSR), is mounted, and hence a limited remote control is thereby provided. The radar search receiver can by a handgrip be removed and interchanged with a binocular if a conventional optical sighting is required.

5.5 Automatic Data Processing.

The information obtained by the sensors is integrated and processed by the SM3 16 bit general purpose computer located in the operators console. The computer has a 48 K memory of which 32 K is used. This computer is already used in the NATO Sea Sparrow systems. The computer can process target data for automatic plotting. The data is based on inputs from an automatic radar extractor, passive sensors and the laser range finder, or manually injected target data.

5.6 Operators Console.

The processing of data, distribution, and presentation is controlled by means of a highly integrated operators console, Fig. 3. The main parts of the console consist of:

- 23 inch Tactical Display
- 12 inch Data Display
- Tactical Operators Panel
- Weapon Control Operators Panel
- Passive Sensor Control Panel

The 23 inch tactical CRT display for presentation of raw radar video and computer generated synthetic information, includes all normal radar display features including true motion and five range scales from 3 to 48 Nm, Fig. 4.

By addition the following special features are to be mentioned:

- Display of target number with predicted target course and speed vectors for selected targets.
- Own ship position history
- Bearing from passive sensors

- Laser range presentation
- Ten reference points
- Calculator functions concerned with time, speed and distance parameters
- Torpedo and missile attack solutions
- Torpedo predicted course and position
- Missile predicted flight-path and position.

The 12 inch data display presents all necessary "Command" data. The most important information is the Common Cartesian Grid (CCG)-target data, Fig. 5, containing target designators, target number, time, common CCG co-ordinates, course and speed, ships allocated to the target and own weapons designations for targets. A similar data tabular can be presented referenced to range and bearing from own ship.

Other presentations selected by the command are:

- Missile data
- Torpedo data
- Attack position data, Fig. 6

Priority can be given to two tracked targets whose data is always presented irrespective of what data presentation is selected.

The presented data is digitalized thus easily enabling data link transmissions to own forces. The received transmissions may then be presented on the data display in the co-operating ships. For automatic data transfer a 75 bd data link is considered sufficient. Both the MSI-80S and the communication equipment are prepared for such a link, but the matter of link compatibility has deferred the decision on link implementation.

Information can be switched between the 12 inch data display and the 23 inch tactical display and vice versa in case one of them fails.

5.7 Main Tasks for the Operators.

THE TACTICAL OPERATOR initiates the target data computations and has control of the tactical display.

Main modus for track initiation is a manual tracking ball function. The target number designation is keyed in by the operator.

There are, however, various other schemes to initiate targets for example initiation of target data computations by means of CCG coordinates received from external sources.

THE WEAPON OPERATOR selects the various control modes for the weapons and sets up and controls the weapon salvos. Two torpedoes against two separate targets can be controlled, while at the same time a Penguin SSM salvo can be launched against a third target or one of the targets engaged by the torpedoes. The operator can choose between straight or angular flight-path for the Penguin missiles, and manual line of sight or collision point guidance modes for the torpedoes. Weapon-to-target designation is target number initiated after which all relevant weapon data is processed and distributed to the weapon to be used.

The weapon operator has for this purpose the following weapon data sections at his disposal:

- Weapon selector
- Weapon control
- Weapon fire section
- Emergency mode

THE PASSIVE SENSOR OPERATOR controls the passive sensors together with the laser range finder. On his request, sensor observations are automatically transferred to the computer for further processing and integration. The stabilized platform, on which the LLTV and laser range finder is mounted, can be either automatically or manually slewed for target acquisition. If a target bearing is already known from the presentation on the tactical display, the sensor platform can be trained directly to this bearing. Once the angular movement of a target has been computed, rate aided tracking can be performed. Fine adjustments to keep the sensors dead on the target will normally have to be done manually by the operator while watching the TV picture on the monitor in front of him.

The laser range finder is manually fired. Three ranges on the same bearing are presented, one range selected by the operator might be transferred to the system.

The platform bearing and laser range is either automatically, or manually transferred to the computer. Provision is made for fast "swapping" between two selected or priority targets.

The monitor and joystick for the TV-tracker system is placed adjacent to the passive sensor operator.

The bearing from the TV tracker may, however, be transferred to the computer, and the TV video can be displayed on the passive sensor operators TV monitor, thus providing an additional sensor mode for weapon control.

Radar Search Receiver intercepts are analyzed by means of an analyzing unit on the passive sensor panel.

5.8 Training and Recording.

Training facilities are incorporated into the system which allow simulation of certain vital functions. These simulations are initiated by manual operations from the control panels.

- Own ship's movement is simulated by manual settings replacing the log and gyro compass.
- Eight fictitious radar echoes serving as targets can be generated and tracked.
- Simulated missile and torpedo firings are performed by switching the weapon systems into a simulated mode.

A dual cassette recorder is built into the console. This is used for programme loading and data recording. The recordings will contain the following data:

- Own ship's movement
- Sensor observations
- Tracking solutions
- Weapon data
- Geographical positions

For a quick review of events and for debriefing purposes, a separate system programme provides replay facilities on the console. Own ship, missile flight-paths and torpedo courses are then drawn on the tactical display. Replay of the recordings are also performed on shore based trainers for tactical evaluation and more profound analysis.

The replay system aboard can be extended to include real-time play-back. The recorded situations are then sequentially repeated on the tactical display. Provisions for fast replay and "freeze event" are also considered.

6. CONCLUSIONS

In order to cope with the threat a highly integrated fire control system had to be developed for the "HAUK"-class FPB.

The corner stones in the described system are:

- Assessment of the tactical situation
- Assistance in decision making
- Threat evaluation
- Actions

The assessment of the tactical situation is achieved by:

- The use of multi sensors (passive and active) in the target tracking process.
- Receiving data from friendly units by the link system
- Accurate navigation by use of inertial sensors in the stabilized platform
- Handling, sorting and correlation of the above mentioned data in the computer in order to present a clear and accurate picture for the CO.
- Broadcasting of synthetic tactical information without delay to friendly units.

The assistance in decision making is achieved by:

- Using the computer to:
 - o Monitor the status of the weapons
 - o Calculate predicted missile flight-path and torpedo course and present the solution on the tactical display
 - o Calculate attack position data (course and speed)
 - o Store geographically fixed reference positions
- The data display showing the following information:
 - o Missile data
 - o Torpedo data
 - o Target data in two pages on range/bearing form
 - o Target data in two pages on CCG form
 - o Course of attack

The evaluation of the threat and the associated actions to be carried out are done by:

- The extensive use of all the information on the operator console (displays, numerical read outs, etc).
- The latest information on action taken by friendly units (link and displays)
- Automatic weapon assignment and control

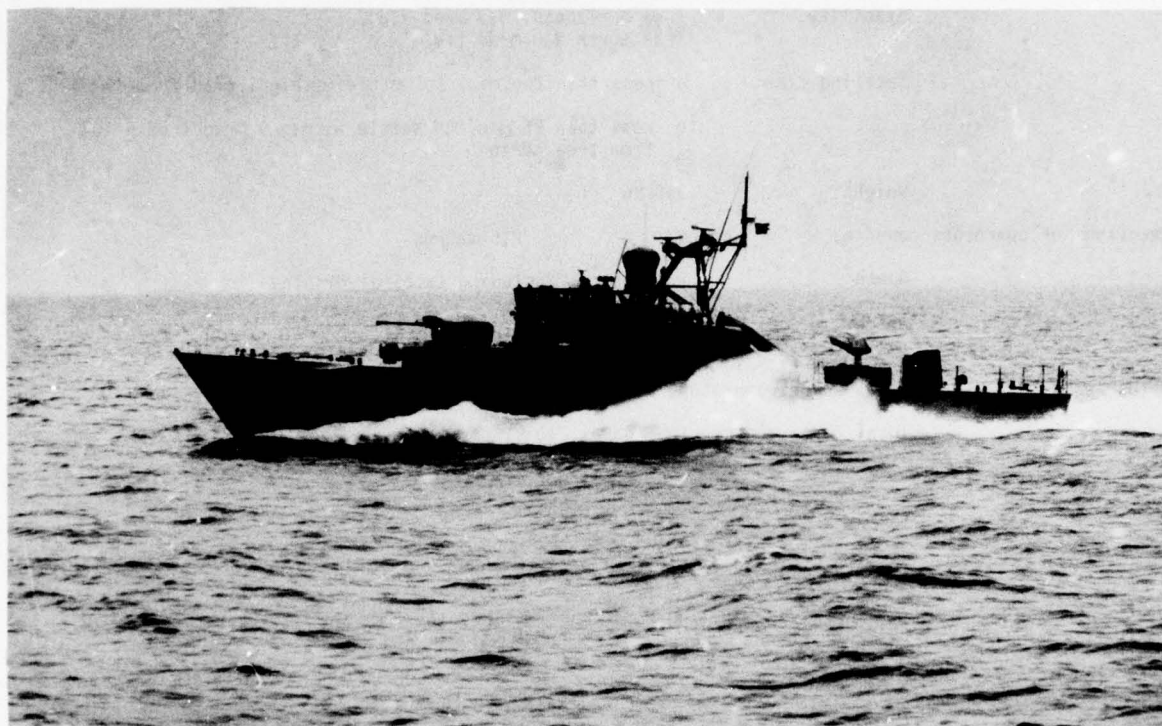
By careful integration of the above mentioned corner stones by the use of modern technology, a highly versatile Weapon Control System has been developed. All obtained information is available for a multitude of users in order to achieve surprise, quick reaction, effective command and weapon control; all vital ingredients to successful FPB operations.

The new "HAUK"-class will be set into service by the end of this year, and we believe that it will be a worthy successor to the RNON's traditions as one of the pioneers in the evolution of small FPB's.

APPENDIX 1

KNM "HAUK"'s Main Data:

Displacement, tons:	120 standard, 150 full load
Dimensions, metres:	36,5 x 6,2 x 1,6
Main Engines:	2 MTU diesels; 7000 hp = 34 knots
Range, miles:	440 at 34 knots
Complement:	22



"Hauk"-Class FPB

EQUIPMENT SPECIFICATIONS

Radar: Solid State Navigation Radar I-band

LLTV Camera: 625 lines, 50 half-frame/sec 4:3 Aspect Ratio, Intensified SIT tube

LRF: Range Accuracy 10 m, Range 30 km

Stabilized Platform: Type: 3 axis

Rotation, Angles: Roll: + 45°
Pitch: + 20°
Azimuth: Unlimited

Rotation speed: 45°/sec

Load: 100 kg

Stability: True horizontal 0,3 mrad (1σ)
True north 9,0 mrad (1σ)

Settling time: o Less than two min. to settle within 1 mrad from 10°
o Less than 25 min. to settle within 9 mrad from $\pm 10^\circ$ from true north

Weight: 350 kg

Dimensions of operators console: Length: 2,6 metres

Depth: 1,75 metres including tactical display

Height: 1,55 metres

Weight: Total weight below deck approx.: 1200 kg
Total weight operators console approx. 1000 kg

Power: Total power consumption approx. 10 kVA from 3 x 115 Volt/60 Hz, Mil. Std. 461.

ENVIRONMENTAL SPECIFICATIONS

SYSTEM AND MAIN UNITS

	Environment	Severity		Test procedure/Remarks
		Functioning during test	Functioning after test	
1.	<u>Vibration</u>			
	a) After region	5-20 Hz: $\pm 1,0$ mm 20-100 Hz 1,6 g		IEC 68-2-6 Test Fc
	b) Main region	5-20 Hz: $\pm 0,63$ mm 20-100 Hz: 1,0 g		IEC 68-2-6 Test, Fc, B1
2.	<u>Shock</u>		2 shocks in each of the main directions ¹⁾	ER-SG
3.	<u>Temperature</u>			
3.1	Equipment below deck			
	a) Low temp.	0°C	-40°C	ER-CC para. 1
	b) High temp.	+55°C	+70°C	ER-CC para. 2
	c) Temp. cycling	0°C to 55°C		ER-CC para. 3
3.2	Equipment above deck			
	a) Low temp.	-25°C	-40°C	ER-CC para. 1
	b) High temp.	+55°C	+70°C	ER-CC para. 2
	c) Temp. cycling	-25°C to +55°C		ER-CC para. 3
4.	<u>Humidity</u>		20-58°C 80-100% RH	ER-CC para. 4
5.	<u>Salt spray</u>		3,5% salt solution 35 \pm 5°C	ER-CC para. 5 test on representative details
6.	<u>Enclosure</u>			
	a) Below deck		Rain proof	ER-CC para 9b
	b) Above deck		Driving rain	ER-CC para. 9c Test II
7.	<u>Ice Formation</u>	Water of 0 \pm 3°C running over the eg. stabilized at -10 \pm 2°C		ER-CC para. 8 15-20 times per hour for 4 hours
8.	<u>Wind</u>		Winds at 40 m/s and wind gusts of 50 m/s	ER-CC para. 10

- 1) Shock loading according to equipment weight
 Example: 240 - 700 kg: T = 3 ms 55 g 27 g, 22 g (Vertical, Athwartship, Longitud.)
 T = 13 ms 13 g 6 g, 5 g (Vertical, Athwartship, Longitud.)

- o ER: Draft Proposal Requirements Royal Norwegian Navy, Feb. 1969
- o IEC: International Electrotechnical Commission Geneva, Suisse,
- o Most of the above mentioned specifications comply with DEF 133 class N1 and N2
- o The only exception from the environmental specifications is the tapes for the cassette recorder.

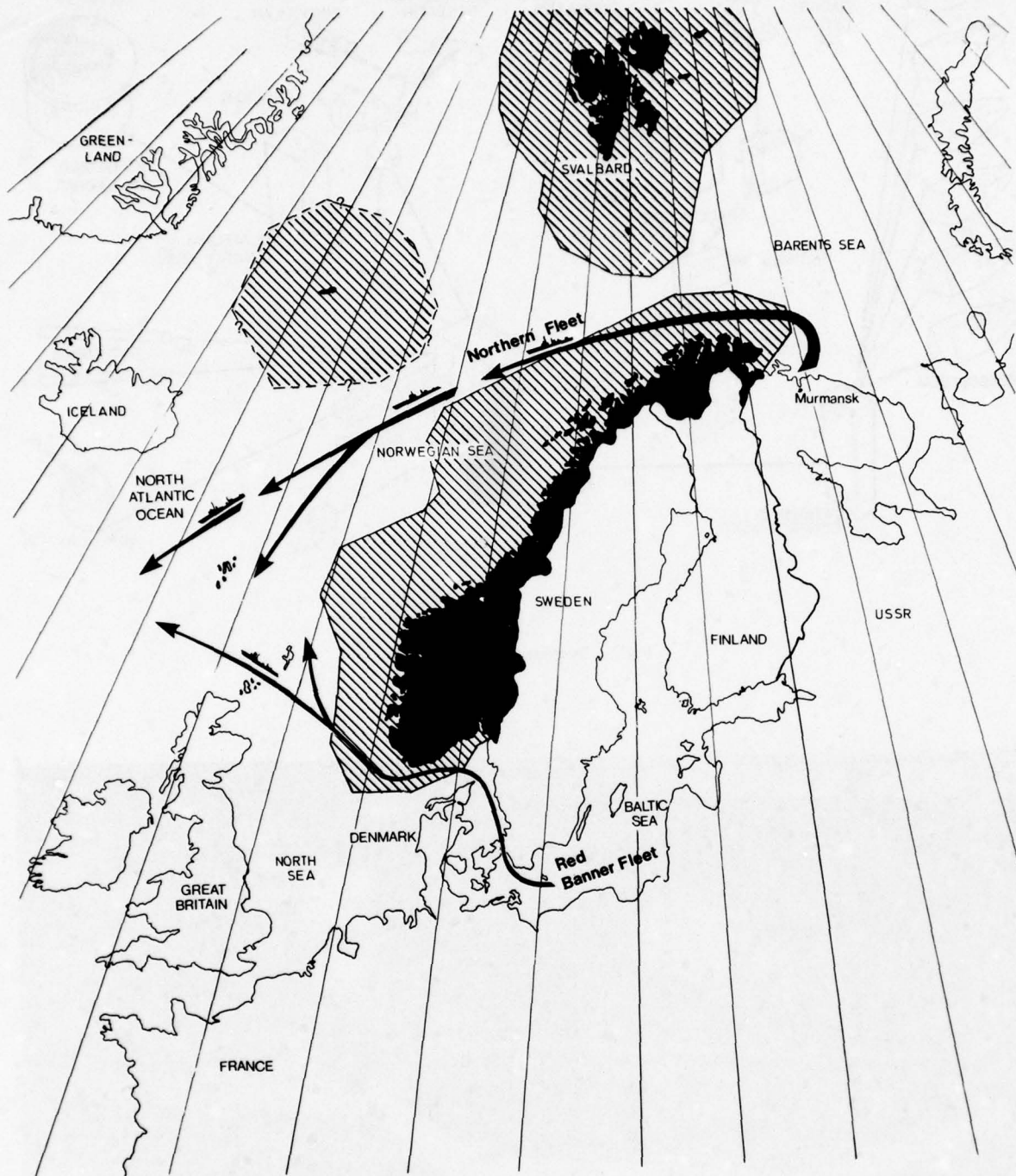


Fig.1 Northern Europe

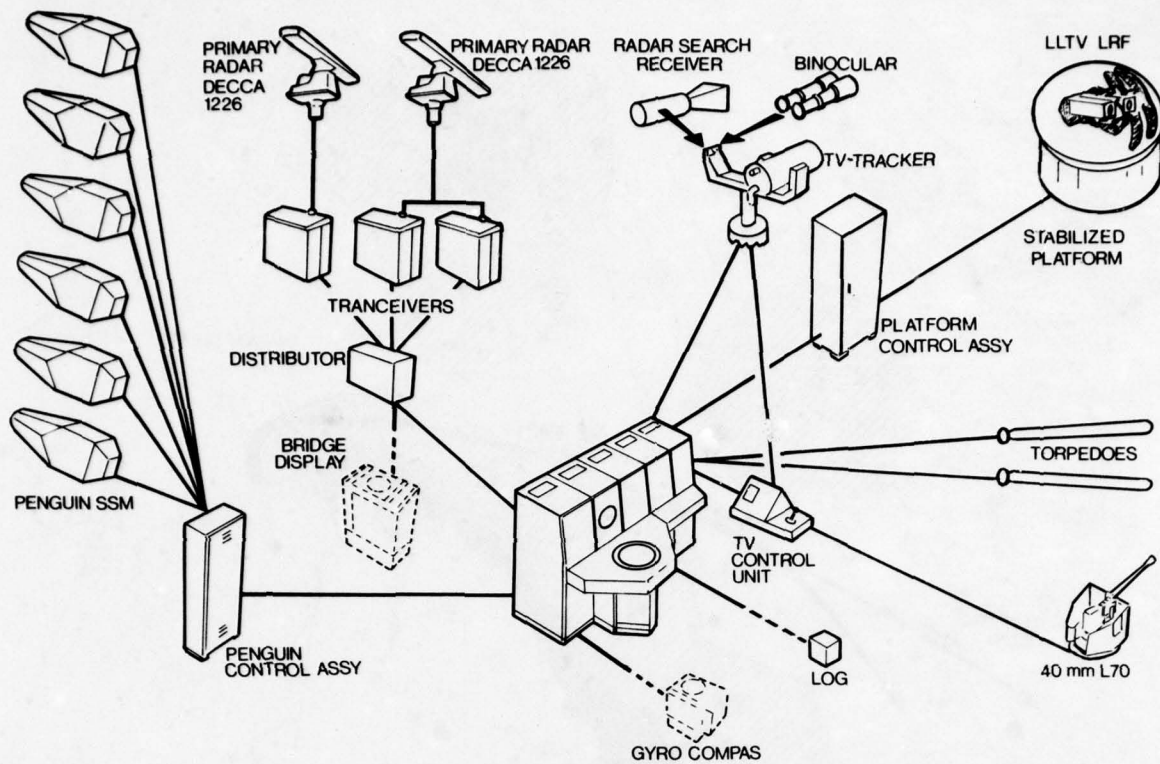


Fig.2 System configuration

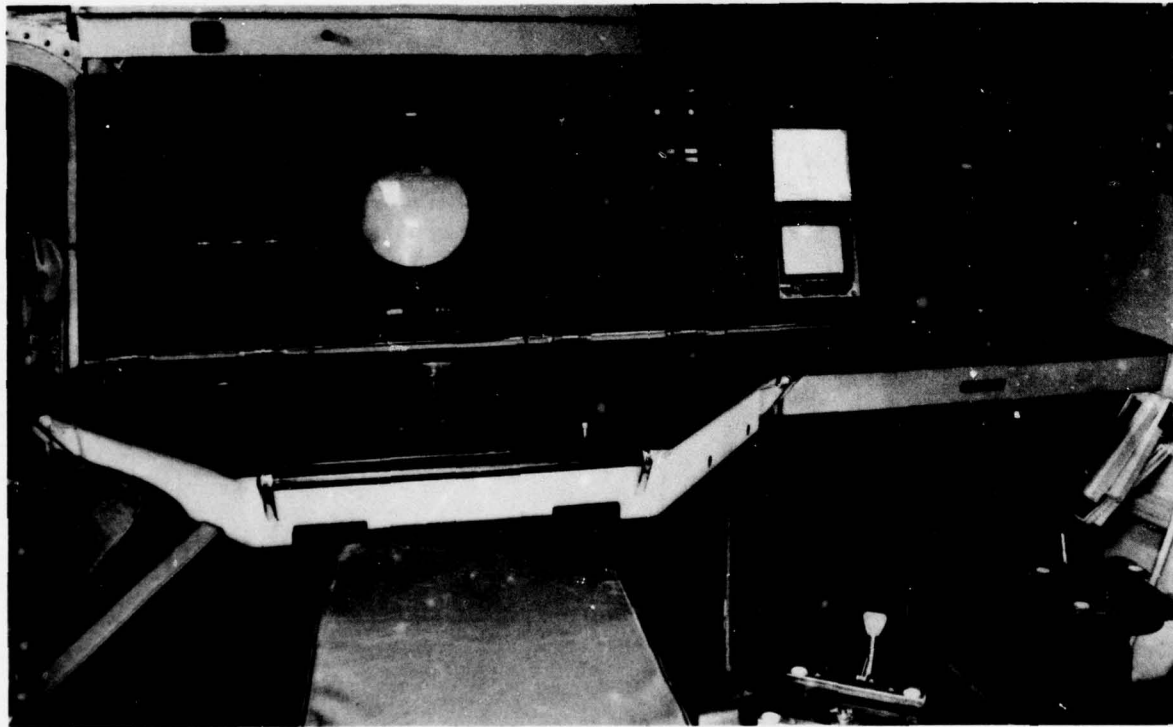


Fig.3 Operators console

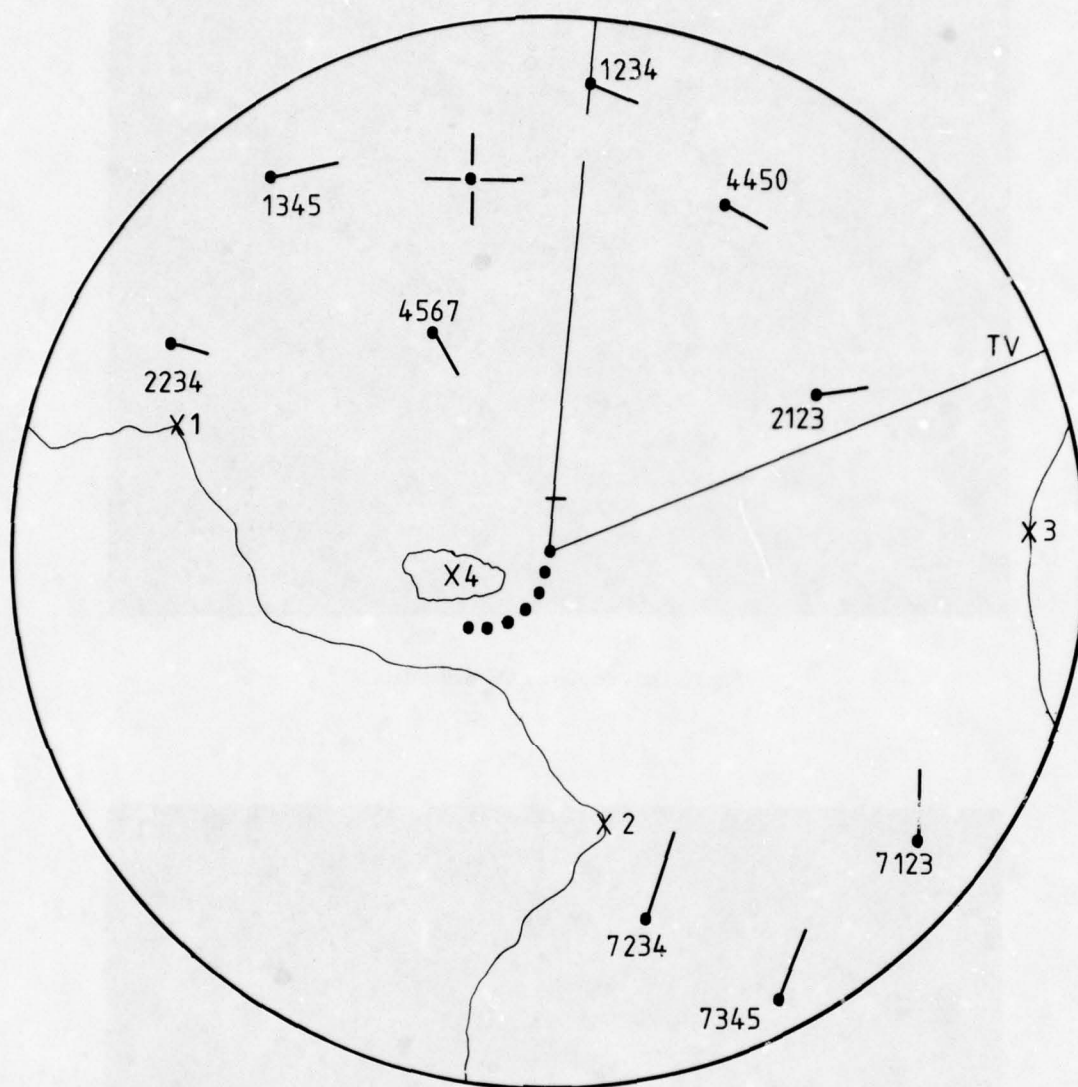


Fig.4 Tactical display

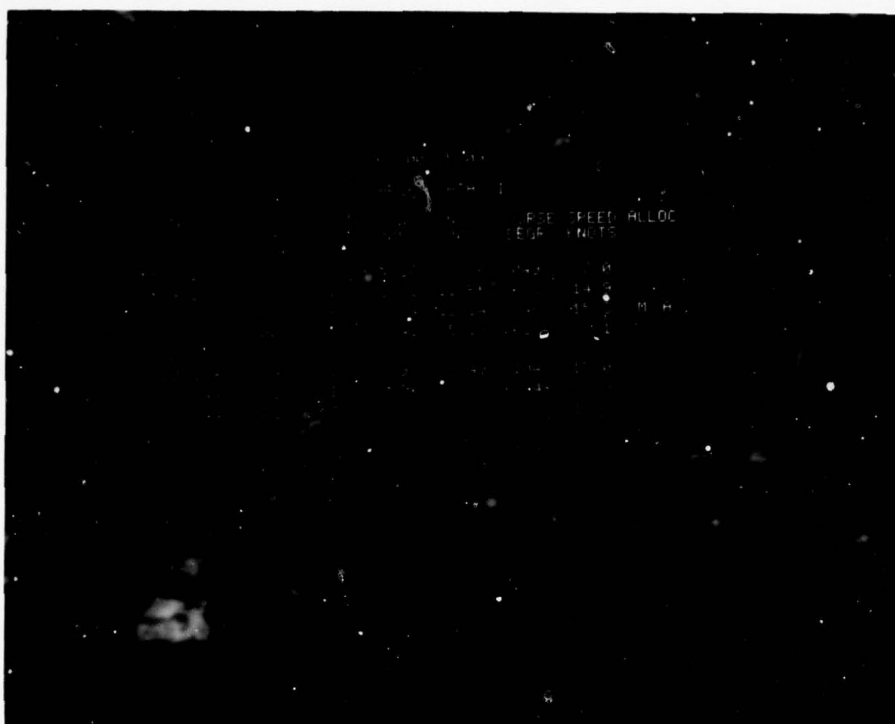


Fig.5 Data display. CCG target data

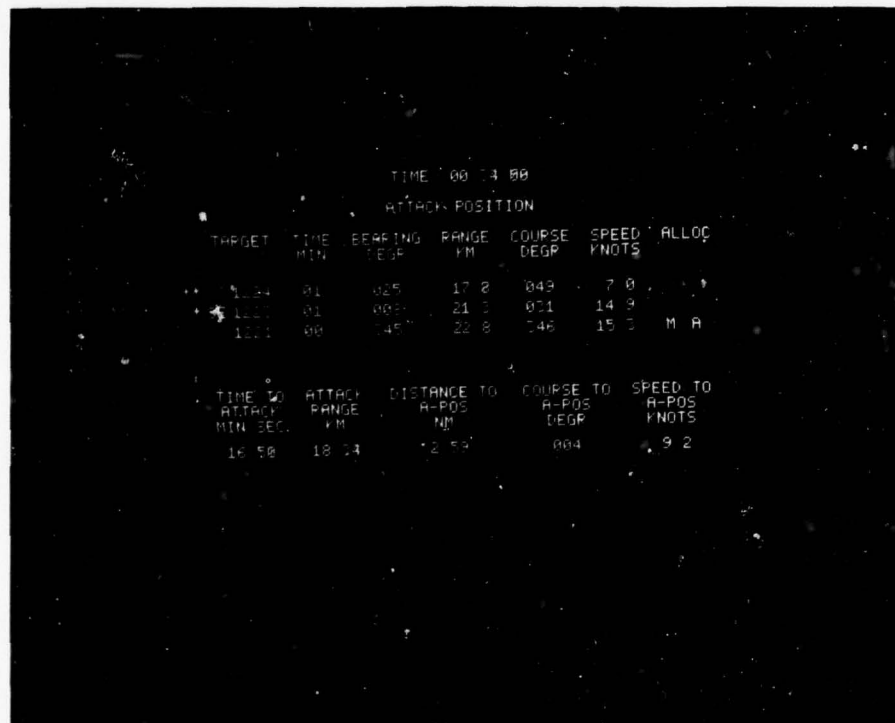


Fig.6 Data display. Attack position data

DISCUSSION

R.C.Makin

It seemed from the photograph of the console that the fire control indicators and controls were hardwired. Is this true?

Author's Reply

All the controls are under software control. Some of the keys have fixed function (text), for instance the Fire-button. Others have multiple functions, where the text is given by the text in film displays, etc.

Y.Brault

If my understanding is correct you intend to have in the future both LLTV and Thermal IR. Is it your intention to display the TV output or the IR output or do you intend to provide a combined image?

Author's Reply

We intend to provide a combined image.

JOINT TACTICAL INFORMATION DISTRIBUTION SYSTEM (JTIDS)

WEAPON DELIVERY APPLICATIONS

BY

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WEAPON GUIDANCE AND WEAPON DELIVERY APPLICATIONS OF JTIDS

SUMMARY

This paper addresses the application of JTIDS, which is a secure communications system, and the tactical data processing of key data within that system, to satisfy a tactical systems requirement of weapon delivery. The capabilities of the JTIDS relative navigation to provide correlated time and position among all community members is especially important in this application. In addition, one of the primary tasks in the application of JTIDS to solving the weapon guidance problem is that of placing the target coordinates into the relative navigation grid.

1. INTRODUCTION

The relative navigation capability of JTIDS is an outgrowth of a previously developed Navy hybrid navigation system called the Integrated Tactical Navigation System (ITNS). However, ITNS lacked the secure data link capability of JTIDS.

The tactical hybrid navigation sub-system within JTIDS allows for the effective coordination of air, ground, and sea based systems through cooperative use of the navigation sensor resources of all members in a tactical community. An integrated communications capability is required in this system approach and is briefly discussed. This concept is based upon the premise that the global sphere of required cooperative vehicle activity may be divided into various tactically self-contained areas within which navigation, communication, and identification of all community elements is required to a more fine grain resolution than that required for global operation. Thus, within the tactical area a common relative navigation grid system with tactically self-contained communication capability is required.

2. JTIDS CONCEPT AND CAPABILITIES

JTIDS provides tactical commanders with standardized interoperable systems by which all members of a tactical community are interconnected in an RF data link permitting jam-resistant crypto-secure communication, precision relative navigation, TACAN, and inherent identification capability. The capability of JTIDS is shared among participants on the basis of time division, using a technique known as time-division multiple-access (TDMA). Each participant in the JTIDS network is assigned a sufficient number of time slots to accommodate the number of messages likely to be required by his mission. During his assigned transmit time slots, each user broadcasts data into a commonly accessible communications data stream represented by a TDMA ring (see Fig. 1). All other elements can extract information of the type they require by continuously monitoring and sampling the data base. The relative navigation capability is provided by making use of onboard sensors. In operation, the dead reckoning equipment senses vehicle motion and the computer calculates position by integration. A position report from a remote unit is received via the JTIDS link and the time of arrival (TOA) of this message indicates the range to the remote unit. Using this information, a correction to the estimate of own position is calculated and applied. In turn, a position report is transmitted via JTIDS for use by other members (see Fig. 2).

The coordinate frame used for position reporting in the relative grid is a tangent plane grid, a rectangular grid tangent to the earth at the origin, which is nominally stationary. The origin and the grid are located arbitrarily, but all members accept the location identified by one member of the community designated as controller. From the transmitted data, the apparent relative position of each community member is determined. If each member's self-contained grid is co-aligned, this apparent relative position should be the same as the relative positions measured by the radio ranging. The difference between the measured and apparent relative position provides the error signals which enable each member to align his self-contained grid to community grid. Thus, members each have accurate navigation in the tactical grid in spite of geographic navigation errors (see Fig. 3).

2.1 APPLICATION OF JTIDS NAVIGATION TO WEAPON DELIVERY

JTIDS relative navigation affords members of the same mission or community the ability to acquire targets, effect rendezvous, exchange position data and deliver weapons effectively and accurately within a designated relative coordinate system. Accurate navigation within the community is accomplished because azimuthal, position, and time correlation exists among the community members. Any member possesses the navigation accuracy by effectively touching any other members with an imaginary stick or, perhaps more significantly, to touch any arbitrary point in the tactical region via other member or members as if a sequence of rods were connected. This is realized through the use of a relative grid which is common among the users

and each and every member positions himself in that grid as well as aligning his axes to the grid and to a common azimuth. Fig. 4 graphically depicts active position filtering.

No member represents an independent entity, but rather is an integral part of a network of users linked together by a precise RF ranging system. Relative position is known so well that this network of members can be thought of as one hybrid navigation/weapon delivery system with distributed sensors. The relative grid provides a single measurement base in which the precise exchange of each member's sensor data occurs. For combat consideration, this means that target positions and other points of interest can be exchanged among members of the community with great accuracy. This same relative grid allows for the distribution of precise geographic position data (e.g., GPS data if available) for direct use by the mutual augmentation of the distribution geographic (velocity) navigation sensors, just as if they were located on the same vehicle (e.g., a Doppler on one vehicle being utilized with an inertial system in a second vehicle to provide a hybrid Doppler inertial capability). Members carrying different sensors and sensor types, with different error signatures, augment each other to provide a hybrid system which is more accurate than any single system element alone.

2.2 JTIDS NAVIGATION GUIDANCE

Another weapons delivery application of JTIDS is the combining of the possible improvements in radar targeting with the guidance of long-range missiles. This application of JTIDS can provide an Over-the-Horizon (OTH) targeting capability using JTIDS information correlated with other sensor information.

This JTIDS weapon delivery system would consist of a long-range weapon and aircraft to provide target position updates and weapon guidance information. The aircraft radars could be used for locating and tracking surface ship targets in near real-time. Onboard computers would process radar bearing and range data to determine the target coordinates in the relative navigation grid.

Missile location would be performed by using the JTIDS round-trip-timing (RTT) capability. This capability permits multiple units to measure range to the missile. The JTIDS relative navigation capability allows each of these units to position tag the range. These position tagged range measurements are then sent to a central unit via the JTIDS data link so that the missile position can be calculated. This capability allows near real-time missile position data. Based upon this missile position and the target position a midcourse guidance update message can be generated.

Periodically these JTIDS midcourse guidance messages would be transmitted and could contain missile and target coordinate data and other data as may be deemed necessary. The missile guidance unit would process the guidance message and combine it with missile autopilot data to determine midcourse guidance corrections. In this way, midcourse errors caused by the buildup of missile autopilot errors and wind and target motion, which build up over the period of flight time, will be greatly reduced. Consequently, area search requirements for target acquisition will be minimized and may even be unnecessary. This system mechanization will make it possible to delay terminal seeker activation until within a few miles of the target and, in addition, it will provide the target selectivity and greater weapon survivability.

2.3 JTIDS AIDED BOMB DELIVERY

The JTIDS system also provides a capability for a high-accuracy all-weather navigation bombing capability for delivery of the standard bomb. A fundamental requirement for this weapon delivery capability is the accurate determination of relative position between the weapon delivery vehicle and the target.

The JTIDS system provides the accurate position data required to achieve the high accuracy navigation bombing capability.

A weapon delivery system, using JTIDS for position determination of the weapon delivery vehicle and the target, and integrated with the existing navigation bombing capability of an attack aircraft, provides a greatly enhanced capability for bomb delivery.

Target position in the JTIDS grid can be determined by a number of methods, such as Flyover Mark or target data, can be provided by other JTIDS-equipped platforms.

Once the target is located in the JTIDS coordinate system, navigation bombing is possible. There are no limitations to the type of delivery or tactics to be used.

A by-product of the JTIDS system is improved velocity accuracy of the weapon delivery vehicle in a coordinate frame related to the target information. Thus the miss distance of a weapon in the navigation bomb mode is decreased as a result of improved position and velocity information. In the conventional method of weapon delivery Heads Up Displays (HUD) and ranging radar, there is also an improvement in weapon delivery accuracy, since the improved velocity accuracy reduces the miss distance of the weapon.

2.4 ANALYSES AND STUDIES

The Naval Weapons Center (NWC) in conjunction with various contractors has performed a number of analyses and simulations in the area of relative navigation and its applicability to solving both the targeting and weapon delivery problem. These studies date back over the past five years and were originally started considering the ITNS hardware. However, they were later directed toward the use of the JTIDS hardware to implement a demonstration system employing this capability. The present NWC program performing work in this area is called JTIDS/Joint Air Weapon System or JTIDS/JAWS.

The Kearfott Division of the Singer Company performed much of the early work for NWC and designed both a system, a Walleye digital autopilot and performed a successful simulation program of this system using the ITNS hardware. They later upgraded the demonstration system design to make it applicable to JTIDS and its waveform structure.

IBM Federal Systems Division also performed numerous analyses and simulations relative to a somewhat different but yet related system mechanization.

In addition to contracted work, IBM performed in-house studies in support of the JTIDS/JAWS effort and has developed hardware to deliver to the Navy for use in laboratory and captive demonstration of the weapon data link. Fig. 5 is a mockup of a weapon data link module proposed by IBM. This specific form factor does not represent the ultimate packing density, but it is merely a first cut at re-packaging their present "Brass Board Unit."

A specific guidance mechanization was developed and documented during this effort. This was later expanded by a contract which NWC had with Ford Aerospace and Communications Corp. The Ford effort referred to as MAGNA II (Microcomputer Application to Guidance and Navigation Aids) was intended to exploit the military application of Ford's low-cost microcomputer. Using the Singer algorithms, Ford mechanized a digital autopilot for the Walleye missile. This was subsequently tested in a flight simulation at NWC.

Recently much of the study effort that has gone into the weapon delivery application of JTIDS has been directed towards the Tomahawk Anti-Ship Missile (TASM) application. Guidance schemes and equipment configurations have been developed and are being studied using the techniques described in this paper to provide this type of missile with an Over-the-Horizon targeting capability.

3. CONCLUSION

This paper has been intentionally kept very general in order to avoid sensitive or classified areas. However, the key point to be made is that the relative navigation capability of JTIDS coupled with the tactical data processing of community sensor data can be used to improve the solution to the overall fire control and ordnance delivery problem.

In addition, a grid locked community of users appears to be another key element in solving many of the other problems of tactical command and control.

A demonstration system concept is shown by Fig. 6 and the overall system mechanization to accomplish this demonstration is described by Fig. 7. Presently this hardware is undergoing system test at the Naval Air Development Center (NADC) in Warminster, PA.

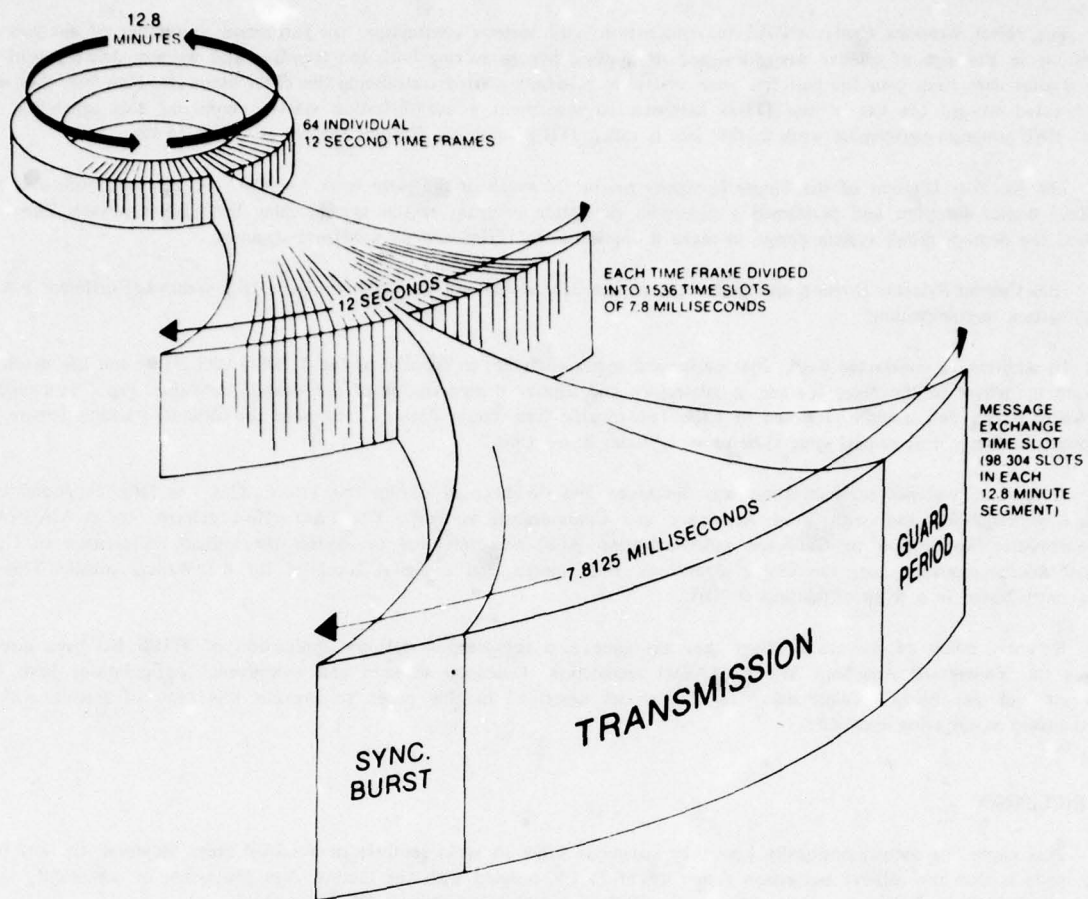


FIGURE 1. TDMA Structure.

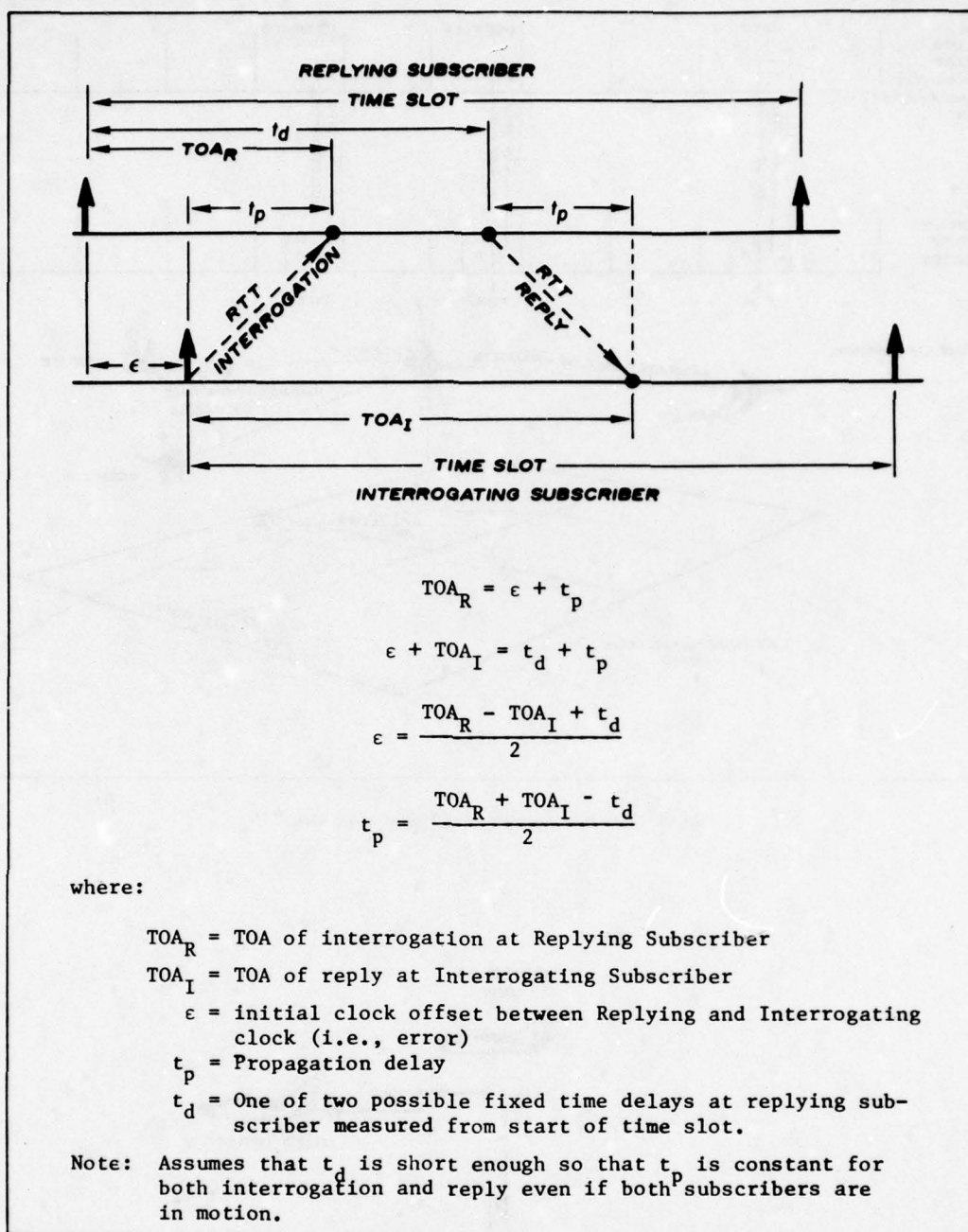


FIGURE 2. General RTT Algorithm.

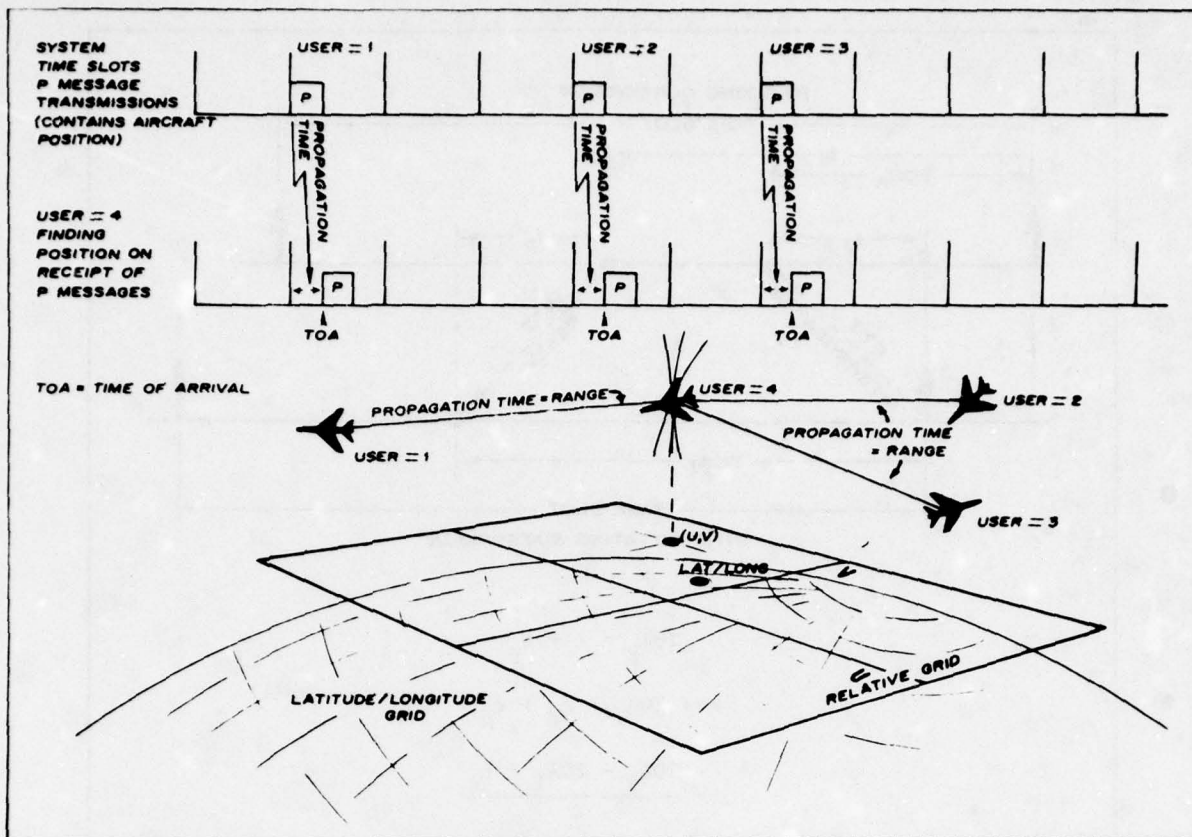


FIGURE 3. Position Location Using Time-of-Arrival Data.

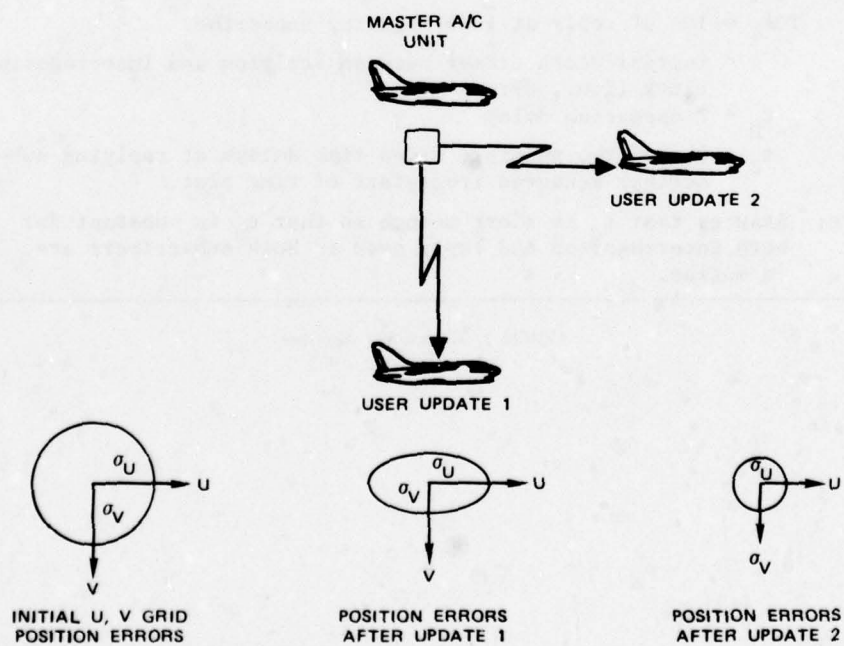


FIGURE 4. Active Mode Grid Position Estimation.

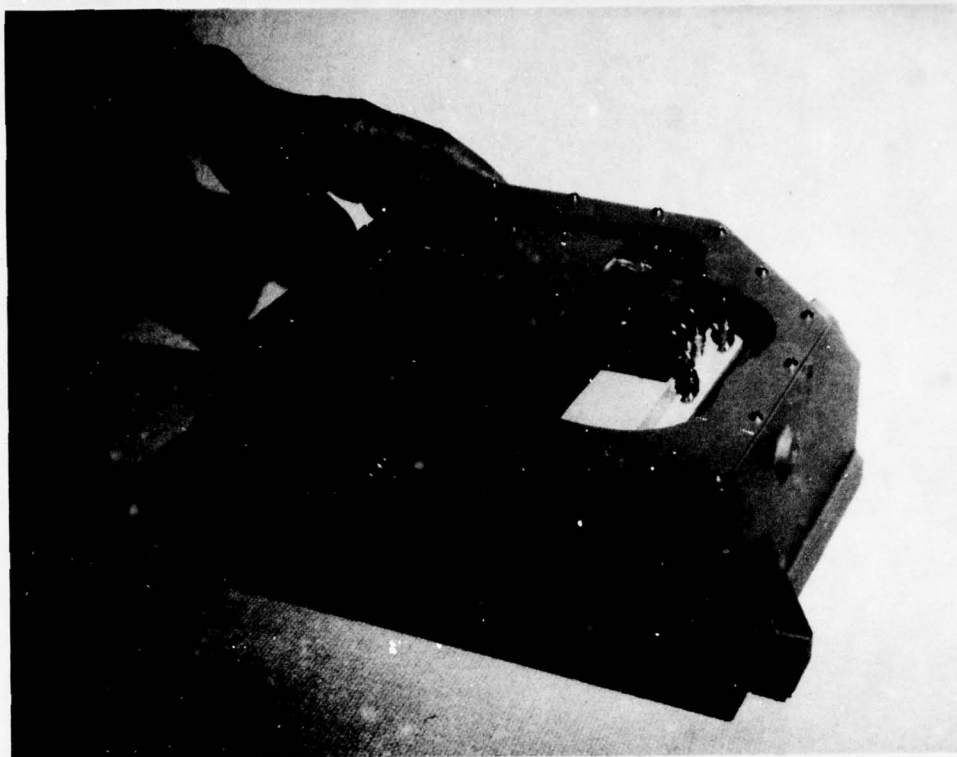


FIGURE 5. JTIDS/Expendable Terminal.

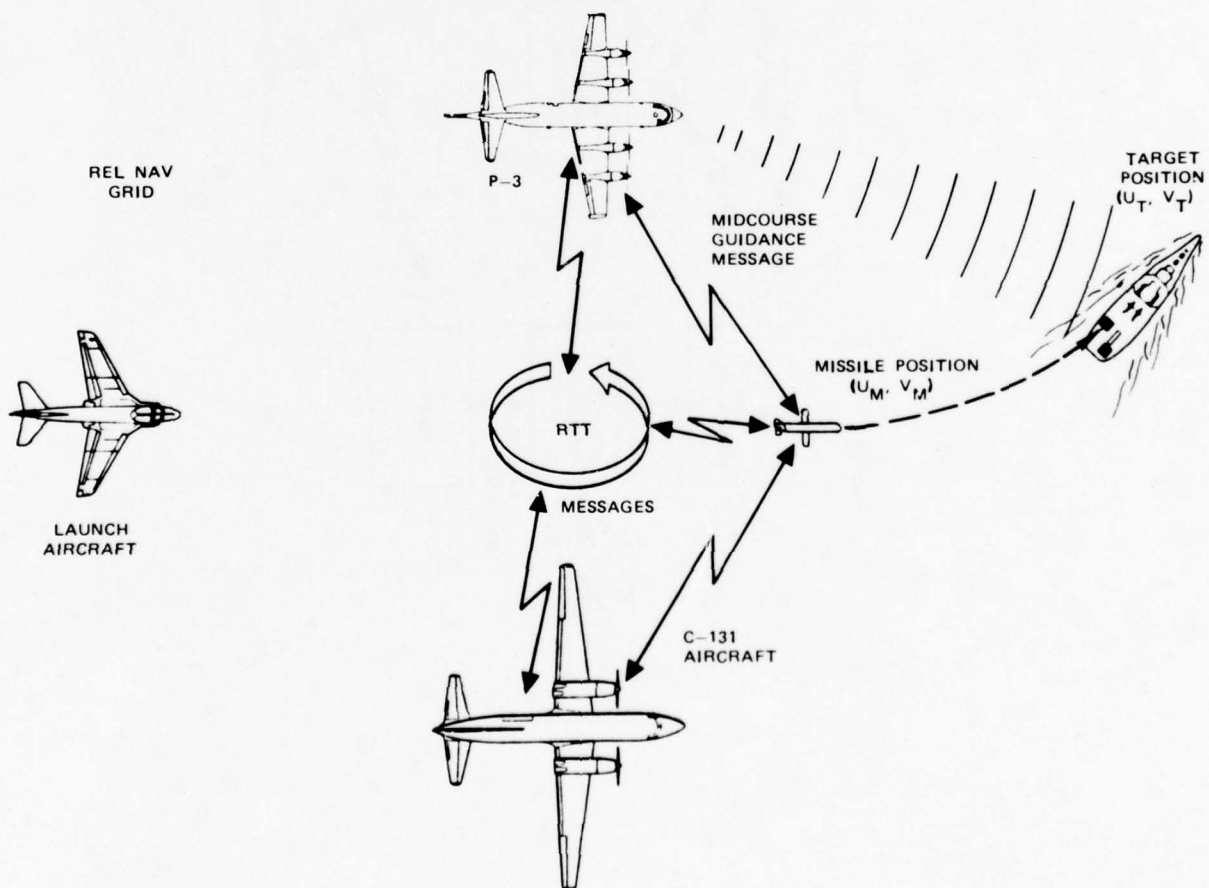


FIGURE 6. JTIDS/JAWS Demonstration Concept.

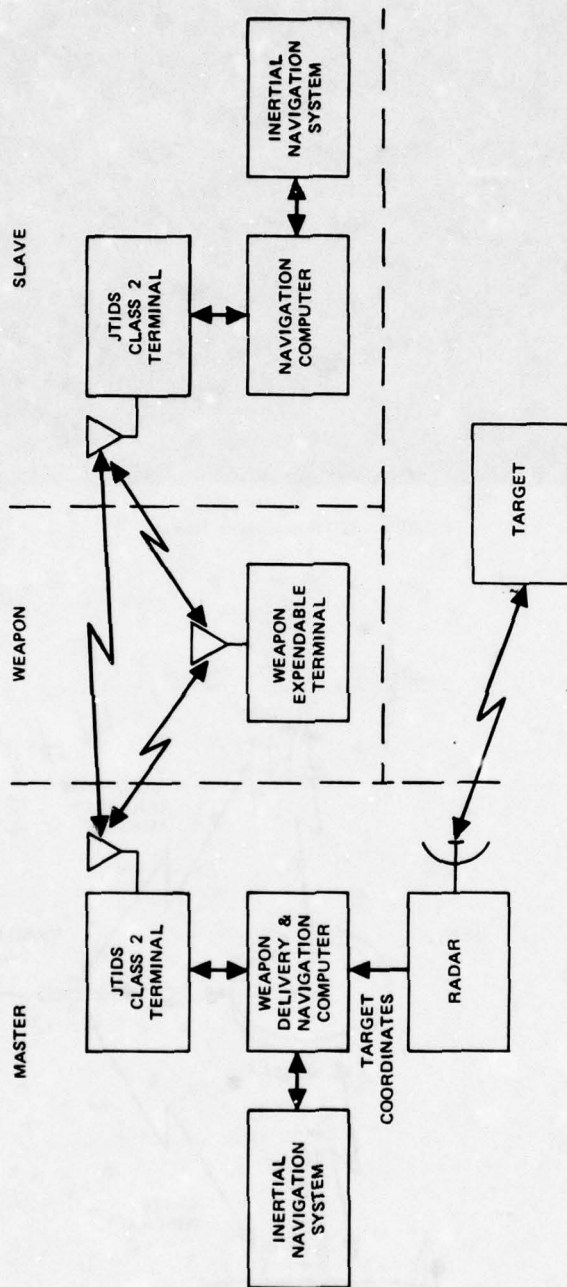


FIGURE 7. Demonstration System Block Diagram.

LES SYSTEMES DE MESURE DE DISTANCE TYPE "DME" ETAT ACTUEL ET DEVELOPPEMENTS FUTURS

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 France

RESUME

La mesure de distance DME permet d'effectuer, avec le VOR, la navigation à moyenne distance. Son utilisation est également prévue pour l'aide à l'atterrissage avec l'ILS et le MLS.

Après un rappel des performances principales fournies par le système actuel, seront évoquées les améliorations apportées aux équipements de bord par l'emploi des nouvelles technologies.

Actuellement, le système est tout à fait satisfaisant, mais il risque de présenter, dans l'avenir, quelques limitations opérationnelles qui peuvent facilement être éliminées. Par exemple, la saturation des balises est évitable en utilisant la technique "DME à sens quasi unique", de même la précision pour l'atterrissage peut être accrue par l'utilisation d'impulsions simples codées en phase, les 200 canaux supplémentaires étant fournis en même temps.

Une navigation précise basée uniquement sur des mesures de distance est envisageable, les données géographiques concernant chaque balise pouvant être transmises sur le canal DME.

1. INTRODUCTION

Le DME constitue la partie mesure de distance du système de navigation à coordonnées polaires standardisé par l'OACI.

L'idée d'un principe de navigation utilisant les coordonnées ρ et θ a été adoptée depuis plus de 30 ans et dès 1949, la fonction azimuth était fournie dans la bande V.H.F. par le VOR alors que la fonction distance était prévue dans une autre bande de fréquence réservée à l'aéronautique de 960 MHz à 1215 MHz.

Vers cette époque, deux systèmes de mesure de distance fonctionnant en impulsions étaient en présence : l'un à large bande (20 MHz par canal) qui eut peu de développement par la suite, utilisait une dizaine de codages différents de l'espacement des paires d'impulsions pour obtenir un nombre suffisant de canaux, l'autre à bande étroite (6 MHz par canal dans les débuts), avec pilotage des fréquences par quartz, se développa et se perfectionna continuellement pour donner naissance au système militaire TACAN qui resta protégé par le secret jusqu'en 1955.

C'est finalement en 1959 que l'OACI adopta définitivement le système VOR-DME utilisant dans son intégralité la partie distance du système TACAN.

Depuis cette date, l'infrastructure au sol en balises fournissant la distance DME n'a pas cessé de s'étendre.

Actuellement, aux Etats-Unis, environ 1000 stations VORTAC et DME sont opérationnelles.

Dans la zone européenne, on dénombre près de 270 stations OACI VOR-DME ou VORTAC opérationnelles auxquelles il convient d'ajouter 230 stations TACAN ou DME réservées à des usages nationaux. On prévoit, dans les années à venir, un total de 350 stations OACI et 280 stations nationales.

En France, 31 stations OACI sur 44 prévues sont actuellement opérationnelles et il y a approximativement le même nombre de balises TACAN sol utilisées par l'aviation militaire. (Voir Fig. 1 et 2).

En ce qui concerne les appareils de bord, le nombre des utilisateurs du DME est évalué à environ 70.000. Ce nombre est en croissance rapide avec le développement de l'aviation d'affaires et de l'aviation générale, où des besoins nouveaux sont créés par l'obligation de s'équiper pour effectuer les procédures dans certaines zones terminales (TMA). En France par exemple, le DME est maintenant obligatoire pour accéder en IFR à la TMA de PARIS et il est recommandé dans les TMA de LILLE et STRASBOURG.

L'utilisation du DME est également favorisée par le large choix d'interrogateurs proposés maintenant sur le marché.

L'extension du nombre des balises DME et surtout des balises VOR crée un besoin de canaux nouveaux, car il existe un appariement rigide et bi-univoque entre les canaux VOR/ILS et les canaux DME/TACAN.

Pour chaque implantation de VOR, une fréquence DME est mise en réserve et l'attribution de nouvelles fréquences n'est pas sans poser de problèmes dans certaines régions.

Il existait, à l'origine, 100 canaux VOR/DME, chacun d'eux ayant une fréquence différente. L'OACI prévoyant les besoins futurs a doublé ce nombre en 1962, pour le DME en introduisant un nouveau code Y de l'espacement des impulsions de chaque paire et en utilisant les fréquences déjà existantes, et pour le VOR en créant de nouvelles fréquences intercalées entre les anciennes portant ainsi l'espacement entre canaux VOR adjacents à 50 kHz.

Les canaux Y sont en fait restés jusqu'à présent peu utilisés, surtout à cause des difficultés de mise en exploitation des canaux VOR associés espacés de 50 kHz. En France, une seule station OACI en canal Y est opérationnelle à l'Aéroport Charles de Gaulle.

2. PERFORMANCES PRINCIPALES DU SYSTEME

Les performances que l'on peut obtenir du DME sont liées au format du signal utilisé, mais elles dépendent également de la qualité des équipements sol et bord que la technologie moderne a permis d'améliorer grandement.

2.1. Nombre de canaux

Ils sont au nombre de 100 en mode X et 100 en mode Y. Dans chacun de ces modes sont prévus :

- 60 canaux couplés aux VOR "en route" ;
- 20 canaux couplés aux TVOR de zones terminales ;
- 20 canaux couplés aux ILS.

Ce nombre de canaux sera suffisant pour la durée de vie du système à condition que les développements du DME de précision pour l'atterrissage ne viennent pas en réduire la disponibilité.

2.2. Portée

La portée maximum obtenue est évidemment variable suivant la classe de l'interrogateur utilisé.

Jusqu'à une distance de 200 milles nautiques, la portée est pratiquement égale à la portée optique correspondant à l'altitude de vol, ceci avec une balise répondant aux normes OACI et un interrogateur de performances minimales pour être homologué en catégorie A (puissance d'émission 250 watts et sensibilité du récepteur : -81 dBm).

Pour une portée supérieure à 200 milles nautiques, un interrogateur plus performant est nécessaire.

2.3. Précision en distance

La précision sur la mesure de distance obtenue couramment avec les équipements de bord modernes est meilleure que $\pm 0,2$ MN (1σ). Cette précision reste pratiquement constante quelle que soit la distance mesurée dans la limite de portée. Elle inclut à la fois les erreurs de la balise et de l'interrogateur, chacune comptant à peu près pour la moitié. Rappelons, pour mémoire, que les performances minimales imposent une précision de $\pm 0,5$ MN ou 2% de la distance.

Depuis l'établissement de cette norme, de grandes améliorations ont été apportées, surtout par le traitement numérique de la mesure de distance et par l'utilisation de circuits spéciaux.

La réduction des erreurs a porté à la fois sur les erreurs de biais et les erreurs de bruit.

Les erreurs de biais ont été réduites en effectuant les mesures de temps au moyen d'une horloge pilotée par quartz, à partir d'un marquage précis du front avant de la mi-amplitude des impulsions et en compensant automatiquement les retards apportés par les circuits à bandes passantes limitées au moyen d'une méthode analogue à une double pesée appelée "impulsions pilotes".

Les erreurs de bruit ont été diminuées dans l'interrogateur :

- par une sélectivité temporelle, en effectuant la poursuite avec une porte étroite (moins de $10 \mu s$) centrée sur les réponses de la balise au moyen d'un asservissement ;
- par filtrage, en intégrant la mesure de distance sur plusieurs cycles d'interrogations-réponses et en corrigeant le retard apporté par l'intégration.

Les erreurs de multitrajets qui peuvent être considérées à la fois comme des erreurs de biais et des erreurs de bruit ont été réduites en effectuant les mesures de temps à partir des fronts avant des premières impulsions de chaque paire avant l'arrivée de l'écho éventuel.

En utilisant les techniques énoncées précédemment, la meilleure précision que l'on puisse obtenir sans complication excessive et sans grever exagérément le prix des équipements est environ ± 80 mètres.

Une étude et une mesure expérimentale des erreurs DME figurent dans l'article de MM. R.W. LATHAM et R.S. TOWNES cité en référence 1.

2.4. Capacité des balises

Les balises ont une cadence d'émission qui leur permet de répondre simultanément à 100 avions. Cette capacité est en général suffisante, cependant dans certaines zones à forte densité de trafic, on a parfois observé une saturation du DME.

La croissance du trafic et l'augmentation du nombre des interrogateurs peuvent, dans l'avenir, aggraver cette situation et nous verrons dans la suite comment éviter cette éventuelle saturation des balises.

2.5. Utilisation de l'information de distance

La distance calculée par l'interrogateur est transmise au calculateur de navigation et aux indicateurs de planche de bord sous forme numérique.

En plus de l'information de distance, certains indicateurs fournissent également au pilote les informations de vitesse radiale et de temps à la station qui sont très appréciées dans les avions non équipés de calculateur de navigation.

Les systèmes d'affichage numérique utilisés dans les indicateurs ont progressé ces dernières années et si les afficheurs mécaniques à tambours ont encore de chauds partisans, les chiffres lumineux sont maintenant bien acceptés des utilisateurs, car leur lisibilité est bonne malgré les fortes variations de luminosité auxquelles sont soumises les cabines de pilotage. Un nouveau type d'afficheur à cristaux liquides spécial pour applications aéronautiques apparaît sur le marché, il réunit à la fois les avantages d'une bonne lisibilité et de faible consommation. Ce sera probablement la solution pour l'avenir.

Les interrogateurs modernes fournissent une information de distance de grande stabilité. Le pilote ne se rend pas compte des pertes passagères du signal dues surtout aux évolutions de l'avion, car il voit défiler régulièrement la distance grâce à une mémoire dynamique qui peut durer jusqu'à 12 secondes. Même si l'absence de signal se prolonge au delà du temps de mémoire et que l'information de distance disparaît, le temps de réacquisition est très bref (de 1 à 2 secondes) lorsque les conditions redeviennent normales. Il est d'ailleurs le même après un changement de canal pour sélectionner une autre balise.

3. EVOLUTION DES EQUIPEMENTS DE BORD

Les équipements DME utilisés pour la navigation possèdent déjà depuis plusieurs années un synthétiseur de fréquence et un émetteur à large bande. L'évolution actuelle concerne surtout l'utilisation d'un émetteur complètement transistorisé et de microprocesseurs pour le traitement vidéo de la distance.

Les développements militaires du TACAN ont fait apparaître sur le marché des transistors UHF pour la réalisation d'amplificateurs de puissance entièrement "état solide" permettant d'éliminer complètement les tubes des équipements. Les avantages résultants sont avant tout une diminution importante de la puissance dissipée et une amélioration de la fiabilité.

Dans le domaine civil, bien que le prix de tels amplificateurs soit encore plus élevé que l'équivalent à tubes, les premiers équipements complètement transistorisés fournissant une puissance supérieure à 500 watts apparaissent aux Etats-Unis.

Le calcul de la distance effectué jusqu'à présent au moyen de logique câblée peut maintenant être réalisé en logique programmée. Cependant, ce traitement ne doit pas être appliqué seulement à la distance, sinon le microprocesseur reste sous-employé et le bilan comparatif est défavorable au point de vue nombre de microcircuits, consommation électrique et coût.

En fait, le microprocesseur peut traiter beaucoup d'autres fonctions et il devient alors tout à fait rentable, car il permet d'améliorer encore les performances de l'interrogateur et de fournir de nouvelles fonctions.

Il peut être chargé d'effectuer les traitements supplémentaires suivants :

- transcodage entre la boîte de commande et le synthétiseur ;
- calcul précis de la vitesse radiale et lissage de cette vitesse ;
- calcul de la distance sol vraie en effectuant une correction de distance oblique au moyen des informations d'altitude de l'avion par rapport à la balise ;
- calcul simultané de la distance à plusieurs balises ;
- calcul de navigation n'utilisant que la distance DME à plusieurs balises, surtout pour équipements d'aviation générale ou d'affaires.

Un modèle de calcul de la position à partir de plusieurs balises DME est donné dans l'article de R.W. LATHAM cité en référence 2.

On doit retenir également une intéressante suggestion faite par ce même auteur pour une utilisation opérationnelle de la navigation rho-rho au lieu de revenir au régime recherche de la distance à chaque changement de station, le calculateur (à microprocesseur) de l'équipement de bord détermine à priori la position de la porte de distance relative à la nouvelle station, ce qui permet d'éviter, au moment de la commutation, le taux élevé d'interrogations utilisé habituellement pour une première acquisition de la distance.

4. LIMITATIONS DU SYSTEME DME

Le DME répond parfaitement aux besoins actuels pour la navigation. Les seules limitations possibles dans le futur concernent la saturation éventuelle des balises et la précision insuffisante pour une application à l'atterrissage.

4.1. Saturation des balises

D'une manière normale, une balise ne répond jamais à toutes les interrogations des appareils de bord. Elle ne peut pas en effet émettre une réponse destinée à un avion donné et simultanément recevoir une interrogation provenant d'un autre avion. Les interrogateurs sont d'ailleurs prévus pour fonctionner avec un taux de réponse nominal de 70%.

Lorsqu'une balise DME a en charge un nombre trop important d'avions équipés de DME, elle répond à chaque avion avec un taux inférieur à la normale. Cette anomalie se traduit à bord par des interruptions d'affichage de la distance et, dans les cas extrêmes, par une impossibilité d'acquiescer la distance.

Plusieurs remèdes sont possibles pour éviter cette saturation :

- augmenter le nombre des paires d'impulsions émises par la balise. Malheureusement, l'augmentation correspondante du taux de charge de l'émetteur et des temps morts de la balise impose une limitation ;
- diminuer les cadences d'interrogation des équipements de bord. Les cadences sont limitées à 150 paires par seconde en mode recherche et 30 paires par seconde en poursuite. En fait, les équipements modernes permettent des vitesses de poursuite jusqu'à 2000 ou 3000 noeuds avec des cadences de 10 à 20 paires par seconde. Il faut remarquer, cependant, que la précision sur la mesure de la distance diminue en même temps que la cadence d'interrogation ;
- il est possible de diminuer beaucoup plus les cadences d'interrogation en associant au DME le système à inertie qui effectuerait un lissage des informations DME fournies à des intervalles de temps qui pourraient être assez longs. Ce principe n'est applicable qu'aux seuls avions équipés de l'inertie. Une telle étude, avec application expérimentale, a été faite, et ses résultats figurent dans l'article de W.E. TANNER cité en référence 3 ;
- une solution plus radicale pour accroître la capacité des balises est l'utilisation de la technique du DME à sens quasi-unique. La balise émet en plus des signaux DME habituels un signal d'horloge basse fréquence très stable constitué de paires ou de triplets d'impulsions codées spécialement. L'interrogateur semblable aux équipements actuels comporte en plus une horloge locale synchronisable sur l'horloge de la balise au moyen de cycles "interrogation-réponse" conventionnels. La cadence d'interrogation normale pendant la phase de synchronisation de l'horloge est ensuite très lente en régime établi. Elle peut ainsi être diminuée dans un rapport 10 sans perte de précision en distance appréciable. Il suffit, en effet, d'utiliser une horloge à quartz ayant une stabilité de 10⁻⁸ pour avoir une durée atteignant 2 secondes entre chaque synchronisation. L'erreur supplémentaire maximum apportée sur les mesures de distance à sens unique est alors de ± 6 mètres (20 nanosecondes..).

La distance à mesurer en mode trajet unique est proportionnelle à la différence de phase entre l'horloge de bord synchronisée et l'horloge reçue de la balise. Elle est calculée au moyen de la mesure du temps écoulé entre l'émission de la balise d'un top d'horloge et sa réception à bord, ce qui correspond au temps de transit du trajet unique balise-avion.

Le système peut s'adapter au DME actuel et il est entièrement compatible.

Cette mesure de distance à sens quasi-unique est très intéressante également pour le système TACAN. Outre l'accroissement de la capacité des balises, elle permet d'augmenter la discrétion radio des avions naviguant au moyen du TACAN (voir article de M. BOHM cité en référence 5).

Le signal émis par une balise TACAN comprend des trains d'impulsions fournissant les références principales et auxiliaires de relèvement (fréquence de récurrence 135 Hz). Ces signaux de référence peuvent être générés à partir d'une horloge à très haute stabilité et constituer le signal d'horloge sol sur lequel se synchronise l'horloge de l'équipement de bord.

Pour effectuer la synchronisation, il faut connaître le temps de propagation du signal de référence provenant de la balise, donc la distance de l'avion à la balise. On peut synchroniser l'horloge, soit en vol au moyen de mesures de distance par interrogations-réponses, soit au sol en positionnant l'avion à une distance connue de la balise. La cadence de "rafraichissement" de la synchronisation dépend de la stabilité de l'horloge embarquée. Il doit être possible avec une horloge très stable et pour des missions de courte durée de n'opérer qu'en mode "trajet unique" et d'observer un silence radio complet. La synchronisation est alors effectuée une seule fois avant le départ en mission.

4.2. Précision pour l'atterrissage

Il est prévu un DME de précision fonctionnant en bande L (962-1213 MHz) associé au système d'atterrissage MLS adopté par l'OACI. La précision en distance nécessaire pour ce DME doit être meilleure que 100 pieds (2 σ). Pour l'obtenir, il est nécessaire de réduire considérablement le temps de montée du front avant de l'impulsion gaussienne du DME actuel (2,5 μ s). La conséquence immédiate est un élargissement du spectre du signal et une difficulté pour trouver un nombre suffisant de nouveaux canaux qui ne perturbent pas les canaux déjà occupés dans cette bande de fréquence par le DME/TACAN.

5. EVOLUTION FUTURE POUR L'ATTERRISSE

Puisque l'amélioration de la précision entraîne inévitablement un élargissement du spectre d'émission, au lieu de continuer à utiliser pour le DME de précision le filtrage fréquentiel et le codage en espacement des impulsions, il serait plus judicieux de profiter des techniques d'étalement de spectre à l'émission et de compression d'impulsion par filtrage adapté à la réception, utilisées dans les transmissions numériques. On obtient alors le système DME à codage de phase. (Nous renvoyons à l'article de S.H. DODINGTON, A. LANG, et J. LEGRAND, référence 4).

5.1. Description sommaire du système DME à codage de phase

Le système fonctionnant au moyen d'interrogations-réponses utilise des impulsions simples de largeur 3,5 μ s aussi bien au sol qu'à bord. A l'intérieur de chaque impulsion, la porteuse HF est modulée au moyen d'une modulation de phase binaire suivant un code pseudo-aléatoire à 31 moments chacun ayant une durée d'environ 0,1 μ s. La modulation numérique est du type PSK (Phase Shift Keying) afin de simplifier les circuits de modulation et d'obtenir la précision maximum. Elle pourrait être du type MSK (Minimum Phase Shift Keying) si on recherchait avant tout une largeur de bande plus faible et un encombrement du spectre moins important. Le choix de 31 moments résulte de l'utilisation d'une séquence pseudo-aléatoire de longueur maximum et constitue le meilleur compromis entre un gain de traitement suffisant, une bonne précision et une simplicité de réalisation des circuits modulateurs-démodulateurs.

A la réception, le signal, après changement de fréquence, amplification et limitation, est traité dans un filtre adapté constitué par un corrélateur à ondes acoustiques de surface. Si le code de la modulation de phase est bien choisi, chaque impulsion du signal utile fournit un pic d'autocorrélation accompagné de lobes secondaires de niveau faible. Tout autre signal indésirable ne fournit en sortie du corrélateur que des résidus d'intercorrélation qui ne sont pas pris en compte par les circuits à seuil situés après le corrélateur. Ces signaux indésirables peuvent être, soit des impulsions ayant le code de phase attendu, mais dont la fréquence HF est décalée (canaux adjacents), soit des impulsions à la fréquence HF sélectionnée, mais n'ayant pas le code de phase désiré (en particulier des impulsions gaussiennes DME/TACAN). Le pic d'autocorrélation du signal utile présente une forme triangulaire dont le temps de montée, très bref, correspond à la durée d'un moment de la modulation de phase (0,1 μ s). Il faut noter que le front avant du pic d'autocorrélation est très peu perturbé par les multitrajets éventuels. Un circuit de déclenchement à seuil effectue un marquage dans le temps à un niveau déterminé du front avant du pic d'autocorrélation. Cet instant précis est utilisé pour la mesure de distance.

5.2. Principaux avantages du système

L'utilisation d'impulsions simples codées en phase à l'émission et du filtrage adapté à la réception procure au système tout son intérêt :

- une grande précision dans la mesure des distances pouvant atteindre 40 pieds (2σ) ;
- une bonne compatibilité avec le système DME/TACAN, c'est-à-dire des perturbations mutuelles négligeables ;
- l'obtention immédiate dans la bande de fréquence 962-1213 MHz, déjà occupée par le DME/TACAN, des 200 nouveaux canaux nécessaires pour le DME de précision.

Une étude, des essais en laboratoire et sur le terrain effectués en France sous l'égide du STNA ont confirmé les avantages exprimés ci-dessus.

Le système DME de précision à codage de phase utilisant les méthodes modernes de traitement du signal peut satisfaire les besoins en mesure de distance pour l'atterrissage pendant plusieurs décennies. Il est techniquement très séduisant et mérite d'être développé dans le futur.

6. EVOLUTION FUTURE POUR LA NAVIGATION

Jusqu'à présent, le DME n'est utilisé pour la navigation qu'associé au VOR, la mesure d'angle étant d'ailleurs primordiale pour le suivi d'une route aérienne. Le DME est en fait capable de jouer un rôle plus important et même de devenir l'aide principale pour un système de navigation ρ - ρ utilisant des mesures de distance simultanées à plusieurs balises.

Ce type de navigation peut maintenant être envisagé, car la couverture DME s'est considérablement étendue.

En France, comme le montrent, en annexe, les cartes établies pour des altitudes de vol de 8000 pieds et 15000 pieds, la couverture est multiple sur la majeure partie du territoire.

Sur l'Europe entière, la densité des balises sera sensiblement identique dans les quelques années à venir.

Aux Etats-Unis, sur 94% de la surface du territoire, n'importe quel point est situé à une distance inférieure à 150 milles nautiques d'au moins une dizaine de stations.

Nous avons vu précédemment que l'information de distance DME est d'excellente qualité et que la précision est pratiquement indépendante de la distance et de la position par rapport à la balise. Cette propriété constitue un avantage fondamental par comparaison aux systèmes angulaires dont la zone d'imprécision augmente en même temps que l'éloignement.

Tenant compte de ces facteurs et des possibilités actuelles de traitement numérique par ordinateur, la Société Air-France a défini un nouveau concept de navigation basé sur un système à multilatération par DME, associé au système à inertie pour les avions qui en sont équipés. Ce concept a fait l'objet d'une étude par MM. G. COLLIN et J.B. RIGAUDIAS, citée en référence 6.

Ce type de navigation nécessite la connaissance à bord des données relatives aux positions géographiques des balises utilisées. Toutes les erreurs éventuelles et les inconvénients entraînés par le stockage de ces données, leur introduction dans une mémoire et surtout leur mise à jour périodique peuvent être évités si chaque balise transmet directement aux interrogateurs son "étiquette", c'est-à-dire l'ensemble des données la concernant. Elle devient alors ce que l'on appelle une balise "étiquetée".

Suivant ce concept de navigation, l'installation de bord type, pour l'aviation commerciale comprend, en plus de l'inertie éventuelle, deux interrogateurs DME identiques fonctionnant en étroite collaboration avec un calculateur de navigation associé à un pilote automatique. Chaque interrogateur est capable de l'agilité de fréquence, c'est-à-dire qu'il peut travailler en partage de temps sur plusieurs balises.

Les systèmes les plus évolués peuvent même être équipés d'une sélection automatique des stations disponibles. Dans ce cas, l'un des interrogateurs que l'on appelle "lecteur d'étiquette" est commuté séquentiellement en réception seulement sur chacun des canaux DME afin de fournir au calculateur la liste des stations à bonne portée. L'autre interrogateur effectue les mesures de distance par rapport aux balises choisies par le calculateur. Le plan de vol est inséré manuellement avant le départ ou au cours du vol s'il doit être modifié.

Ce concept de navigation par multilatération est bien sûr compatible, pour l'aviation générale, avec une précision du même ordre de grandeur.

Dans la configuration la plus simple, sans calculateur de navigation, un seul interrogateur équipé d'un microprocesseur calcule simultanément la distance à plusieurs balises sélectionnées manuellement et fournit les coordonnées géographiques. La navigation est faite au moyen de cartes établies pour permettre une bonne facilité de lecture. Partant de cet équipement minimal, un interrogateur plus évolué ayant un calculateur de route simplifié peut permettre de naviguer de balise en balise. Toute une gamme d'équipements de complexité croissante peut ainsi être envisagée jusqu'à un maximum capable d'effectuer une navigation automatique.

7. TRANSMISSION DE DONNEES PAR LE DME, BALISES "ETIQUETTES"

La transmission sol-air des données est effectuée sous forme numérique, sur le canal de la balise par émission d'impulsions gaussiennes supplémentaires.

Les informations principales transmises sont :

- les coordonnées géographiques du lieu d'implantation de la balise :
 - . latitude (comportant 7 caractères pour une précision de la seconde d'arc)
 - . longitude (comportant 8 caractères pour une précision de la seconde d'arc)
 - . altitude (comportant 2 caractères pour une précision de 100 pieds)
- la déclinaison du lieu (2 caractères pour une précision de 0,1°) ;
- le canal DME sur lequel fonctionne la balise.

Pour transmettre les données, deux méthodes peuvent convenir :

- la première consiste à ajouter une impulsion simple supplémentaire après une paire normalement émise par la balise (réponse ou remplissage aléatoire). Le triplet ainsi formé constitue un bit de donnée. La valeur du retard de l'impulsion simple par rapport à la paire détermine le poids du bit.
- La cadence de transmission et par conséquent la charge supplémentaire de la balise peut être ajustée à la valeur désirée, car il n'est pas nécessaire de transmettre un bit pour chaque paire émise normalement ;
- suivant une autre méthode, la transmission peut être faite en même temps que l'émission des signes du code morse de l'indicatif. Il suffit de moduler en position chaque paire d'impulsions d'égalisation émise après les paires récurrentes à 1350 Hz. Ce dernier type de transmission présente l'inconvénient d'être limité en capacité aux 5 informations indiquées précédemment sans possibilité d'extensions futures.

Quel que soit le type de transmission utilisé, les données sont découpées en mots successifs comportant chacun un signal de synchronisation, une adresse, le message proprement dit et un ou plusieurs bits de parité permettant une détection d'erreur. Une redondance par répétition de chaque mot assure à la transmission une grande sécurité.

Le système de transmission de données est entièrement compatible avec le DME actuel. Son adjonction aux balises opérationnelles est simple, il ne nécessite que l'addition d'un codeur. Le décodage des informations à bord ne sera effectué que par une nouvelle génération d'interrogateurs spécialement adaptés à la navigation ρ - ρ .

8. CONCLUSION

Le système DME fonctionnant en impulsions au moyen d'interrogations-réponses a maintenant 30 ans. Il a atteint sa maturité, mais pas la limite de ses possibilités et il est sûrement appelé à se développer encore dans l'avenir.

Pour ses applications à la navigation ρ - θ pratiquée actuellement, son évolution sera limitée aux perfectionnements technologiques des équipements qui amélioreront peu à peu ses performances.

Le développement de la navigation ρ - ρ à base de mesures exclusives de distances est susceptible de lui apporter un nouvel essor, autorisant, grâce à sa précision, une diminution des espacements entre avions.

Dans le domaine des aides à l'atterrissage, le DME jouera un rôle important, car il sera associé à l'ILS et au futur MLS. Des progrès considérables seront peut être apportés au système par l'utilisation des techniques modernes d'étalement du spectre.

9.

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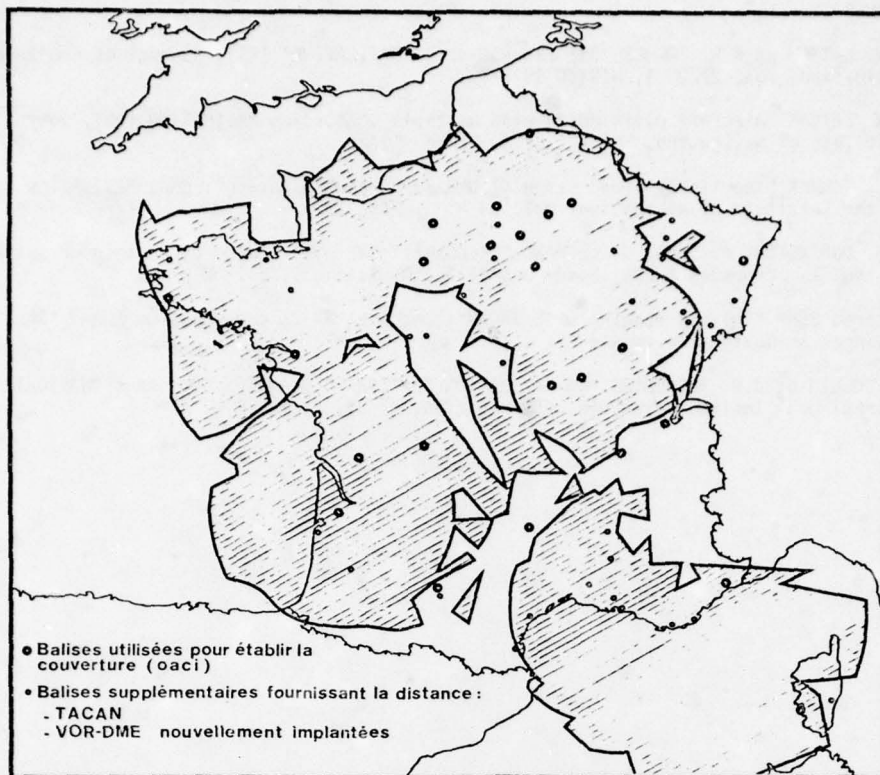


Fig. 1 - COUVERTURE MULTIPLE VOR-DME ET VORTAC
ALTITUDE 8000 PIEDS.

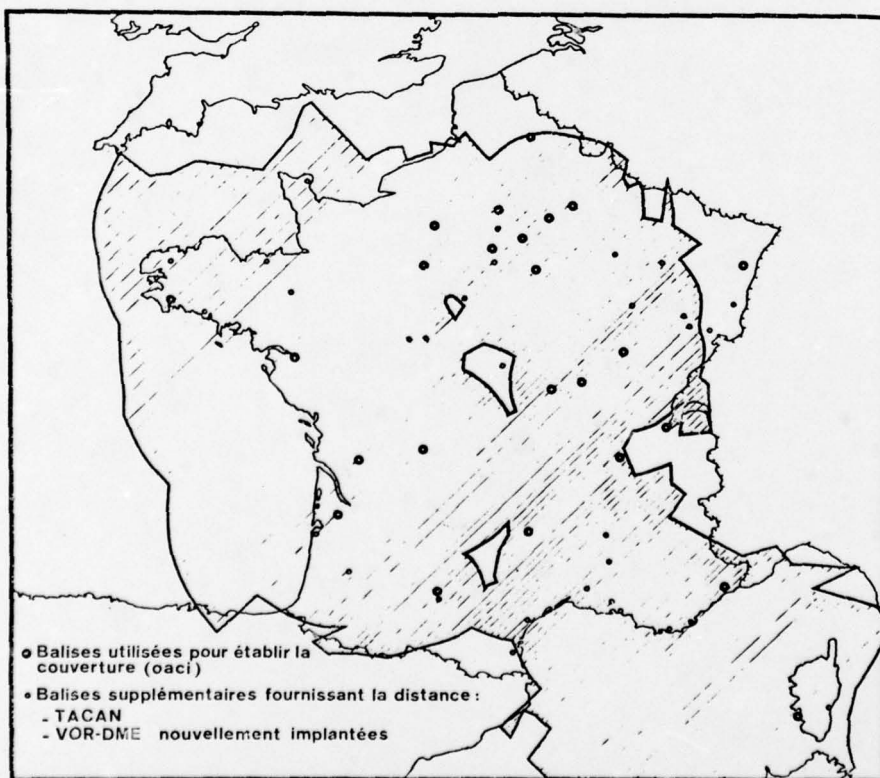


Fig. 2 - COUVERTURE MULTIPLE VOR-DME ET VORTAC
ALTITUDE 15000 PIEDS.

TACTICAL INFORMATION EXCHANGE SYSTEM

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SUMMARY

The Communication, Navigation, and Identification (CNI) requirements of military aircraft have long been satisfied by an implementation of the universally accepted black box approach. This conventional solution to an increasingly complex problem has inherent limitations which have given rise to the development of a totally new system architecture. This architecture is embodied in the Tactical Information Exchange System (TIES), and it is driven by the primary goals of improving reliability, maintainability, flexibility and reducing size and weight. The unique partitioning of the system takes advantage of the latest advances in digital and RF technology and insures against premature obsolescence. Every attempt is made to share hardware resources by developing a family of multifunction programmable modules, including broadband RF components and an all digital general purpose signal processor.

Efforts to date in the exploratory development program have resulted in a clear definition of the baseline architecture, fabrication of breadboard hardware for many of the key elements within the system, and theoretical analysis to evaluate various design alternatives. On going work in each of these areas continues towards the ultimate goal of total system integration and validation of the TIES concept for application in the next generation of Naval aircraft.

BACKGROUND

The communications, RF navigation and identification functions performed by military aircraft remained rather simple up until about the time of the Vietnam War. Transfer of command and control information was primarily done in the military UHF band (225-400 MHz) through voice communication using conventional amplitude modulation. Pulsed type transmissions in the Lx band (960-1215 MHz) were used for RF navigation and IFF (identification, friend or foe). The former was performed through TACAN (Tactical Airborne Navigation), a distance measuring equipment using fixed and mobile beacons, while the latter utilized a discrete code address system which identified friends by their responding to the proper code address of the day. Patrol aircraft, which required information transfer beyond-line-of-sight communications, used the HF band (2-30 MHz) for sending teletype or voice modulated RF signals.

Advances in digital and solid state technology have led to enhanced capabilities in computational and sensor functions, thus providing additional information desired by higher command authorities. Every addition of a new or improved function required the addition of a new functional equipment. If one projects into the 1990 time frame there will be an expected wide use of SATCOM (Satellite Communications) spread spectrum type communications in the VHF, UHF, and Lx bands, an advanced IFF system called DABS (Discrete Address Beacon System), GPS (Global Positioning System), and Collision Avoidance. All of these functions are in addition to those mentioned previously. To support these improvements the size and cost of airborne platforms would continue to increase significantly using conventional design approaches.

Implementation of a totally integrated CNI system for military aircraft would in itself be a major achievement. The TIES concept goes much further in that it is structured around a new system architecture which will satisfy the need for improved reliability, maintainability, flexibility and lower life cycle cost. In addition, it offers a significant reduction in size and weight when compared to a conventionally built system with the same set of functional requirements. There is no new waveform definition in TIES. It is instead an advanced concept for processing the information transfer requirements that will be imposed on the airborne Navy platform for the 1990 time frame and beyond. Figure 1 gives an indication of the multitude of functions and the total RF spectrum which must be considered for the next generation platform, especially in view of the trend toward a multimission type of aircraft such as VSTOL. Present day aircraft are each equipped with customized sensors, computers and communications devices which address their particular mission. There are, for example, anti-submarine warfare (ASW), attack, intercept, reconnaissance and electronic warfare (EW) aircraft, each with a customized avionics suite as shown in Figure 2. The multi-mission platform concept dictates an increased number of CNI functions which a given aircraft must perform in an attempt to satisfy naval aviation requirements while keeping the cost down. It implies that future avionics systems must be capable of simple and rapid reconfiguration, thus allowing any platform to use a variety of sensors for other than its primary missions should the need arise. In addition, early obsolescence must also be avoided through the choice of a system architecture which is flexible enough to keep pace with technological advancements by simple modular substitutions.

SPECIFIC PROBLEMS WITH CONVENTIONAL CNI SYSTEM DESIGN

A simplified block diagram for conventional processing of a typical communication function is shown in Figure 3. The only standardization attempted is to usually confine the dimensions of each subsystem to a so called standard ATR size or some fraction thereof. Normally a "system design for a particular function consists of a series of several Weapon Replaceable Assemblies (WRA's) or commonly called "black boxes". Improvement in a platform's

operational capability has traditionally involved a complete redesign of the hardware. Often separate equipments exist for two or more functions operating in the same frequency band. TACAN, IFF, and the proposed JTIDS (Joint Tactical Information Distribution System) for example, could share the same synthesizer and power amplifier design if designed properly. The same holds true in the UHF band where there are a multitude of transceivers, (ARC-159, ARC-143, ARC-156, etc.), all sharing the same part of the RF spectrum to perform slightly different functions. As a result, acquisition costs are inflated because of the nonrecurring engineering which is duplicated for each new function. Life cycle costs are inflated because of the need for specialized test and support equipment for each subsystem, e.g., TACAN simulator, IFF simulator, Link 11 simulator, Link 4 simulator, etc. There are also unique training requirements associated with each subsystem and a proliferation of non-standard modules which must be stocked, thus causing a logistics support problem and impairing maintenance capabilities.

The conventional design imposes a size and weight burden on the platform because of the need to carry hardware which is required for only parts of the mission. An ocean surveillance platform, for example, may have a projected requirement for up to forty different information transfer functions. An analysis of the instantaneous number of operations needed during a mission may show that only six functions are required simultaneously. There is no way to take advantage of this low percentage of mission utilization time for some functions with the dedicated black box approach. Another difficulty with the standard avionics design is the inability to upgrade system capability with technological advances. If for example, a significant improvement in the efficiency of a high power Lx band amplifier were achieved, it could not be readily incorporated into any existing hardware without costly redesign. Quite often this causes premature obsolescence to occur during the procurement cycle of a particular system.

The last criticism of the present aircraft CNI design to be discussed here is the abrupt loss of function which can occur through hardware failure. With the conventional approach, if a critical function such as IFF is lost, the mission must be aborted even though the aircraft may otherwise be capable of performing its mission. The only way to achieve modes of failure other than complete loss of function is to carry fully redundant equipments. The alternative is a totally integrated CNI design which allows for an overall system failure mode of "graceful degradation", i.e., reassignment of hardware resources on a priority basis through fault isolation.

TIES SYSTEM ENGINEERING

The key element of success for the TIES program is the definition of a new system architecture which tackles straight on the problems resulting from the conventional CNI design. This architecture is shown symbolically in Figure 4. It provides significant advantages over the conventional approach by:

- (1) Utilizing a family of multipurpose, programmable modules which can be used for processing all CNI requirements and eliminate costly redesign.
- (2) Reducing logistics requirements by eliminating the need to stock a large variety of non-standard parts.
- (3) Improving maintainability by incorporating a well designed Built-In and External Test philosophy, simplifying training requirements, and eliminating a wide variety of test and support equipment.
- (4) Eliminating the threat of early obsolescence and allowing for functional expansion or contraction through the use of modular resources and the interconnecting signal distribution subsystem.
- (5) Not allowing a single module failure to cause abrupt loss of function, i.e., graceful degradation is inherent in the design.

A description of the system architecture must begin with a definition of the three basic subsystems in TIES as shown in Figure 5. They are:

- (1) The Frequency Conversion Subsystem
- (2) The Signal Distribution Subsystem
- (3) The Signal Conversion Subsystem

The design of each subsystem is driven by a desire to realize all of the advantages listed above.

The Frequency Conversion Subsystem consists of the antenna subsystem and the front end RF/IF hardware used for transmission and reception. The Signal Distribution Subsystem consists of a wideband FDM (Frequency Division Multiplex) bus and a digital control bus. The FDM bus, which is a key element within the TIES architecture, provides the link between the Frequency Conversion Subsystem and the Signal Processing resources of the system. The digital control bus interconnects the programmable modular resources to a master or executive controller. Finally, the Signal Conversion Subsystem is the name given to the digital signal processing hardware at the source/sink end of the system. The signal flow for a typical

received signal is shown in Figure 4. Depending upon its RF band (UHF in the example shown), it enters through part of the antenna subsystem into an RF front end amplifier/receiver located in very close proximity to the antenna. It goes through the first stages of filtering and amplification and is then down converted to a standard 70 MHz IF frequency.

It is then launched onto the FDM bus cable through an on-bus coupler unit. This device also amplifies, filters the signal and upconverts it into an appropriate frequency slot for distribution on the wideband FDM cable. The signal is then extracted from the FDM cable on the signal processing end of the system by an off-bus coupler unit which basically performs the inverse operation of the on-bus coupler, i.e., downconversion back to the standard 70 MHz IF, filtering and amplification. It then enters one of the signal conversion units, where the waveform is converted back to a baseband signal and distributed to the appropriate user interface through a data processor. The data processor performs tasks such as error correction and encoding, data formatting for display or I/O (input/output) buffering to the related sink. In the transmit mode, the signal flow is reversed and the signal processing elements become signal generators. A detailed description of each of the three basic subsystems of TIES follows.

Frequency Conversion Subsystem

The current baseline for the TIES Frequency Conversion Subsystem consists of four bands of RF coverage, Lx Band (960-1215 MHz), UHF band (225-400 MHz), VHF band (30-225 MHz) and HF band (2-30 MHz). Within each of these bands there are multiple receiver requirements which are satisfied by cascading programmable analog modules such as synthesizers, IF amplifiers, and filters. Any in band waveform can be processed through any one of these multiple receive channels. Every attempt is made to use the same modular components across the four frequency bands as well as within each band. The programmable IF amplifier shown in Figure 4 is an example of such standardization. All of the received signals are downconverted to a 70 MHz IF center frequency before they are coupled to the FDM signal distribution bus. In the transmit mode a particular set of RF/IF resources are utilized in each band to provide RF drive, selectivity, high level modulation, and RF power amplification. The input to the transmitter chain is a standard 70 MHz signal from the FDM signal distribution bus. The programmable hardware of the frequency conversion subsystem is controlled by the remote microprocessors shown in Figure 4. Front end channel tuning, IF bandwidth, and gain are some of the parameters which are under microprocessor control. Other features of the Frequency Conversion Subsystem afforded by the modularity and programmability of the hardware resources are a powerful built-in-test scheme and a fail-soft mode in the event of front end failure. In a typical case, a failure in the first RF amplifier would be detected using the remote pilot generator and fault isolation software. Signal bypass hardware could then be activated to circumvent the problem, although with reduced performance such as degraded receiver sensitivity. In this case, there would still be enough sensitivity to allow, for example, emergency navigation capability.

The remaining major element of the Frequency Conversion Subsystem to be discussed is the Antenna System. No detailed antenna design has yet been formulated, however, the considerable development underway in directed and adaptive array techniques is being closely monitored. Algorithms for adoption of arrays can be incorporated within the TIES architecture to provide phase and amplitude adjustments to the antenna elements. Parameters not normally available to adaptive arrays, such as channel measurement and error rate measurements, can also be incorporated with the antenna algorithms to provide better performance. Arrays also have the advantage in that they can be programmed for the mode of operation desired. Omnidirectional, sector scan, directed beam, or adaptive antennas can all be implemented with a set number of antenna elements. The ultimate antenna design for TIES will be directed towards providing a multiband system which is flexible enough to meet all of the CNI waveform requirements.

Signal Distribution Subsystem

The Signal Distribution Subsystem is composed of a wideband FDM bus and a digital control bus. The FDM bus is fundamental to the TIES architecture. It provides the basis for the flexibility, modularity, and distributed nature of TIES. Through the FDM bus any set of RF/IF resources in the Frequency Conversion Subsystem can be connected to any set signal processing resources in the Signal Conversion Subsystem. The concept of graceful degradation is dependent on this feature. The FDM bus also allows the RF/IF package to be placed in very close proximity to the antenna which even by a very conservative estimate can eliminate 3 to 5 db of transmission line loss between the receiver/transmitter and antenna port. This 3 to 5 db translates directly into size, weight and prime power savings. Flexibility is achieved through the FDM bus approach since sets of modular hardware for both the Frequency Conversion and the Signal Conversion Subsystems can be added or removed from the system with relative simplicity. The bus is analogous to a practical, low cost CATV distribution system. It consists of a series of on/off bus coupling units and separate transmit and receive signal cables. The coupling units are synthesizer/filter combinations which allow standard 70 MHz IF signals to be upconverted to the bus channel assignment for the transmit bus or which downconvert the bus assigned channel to 70 MHz coming off of the receive bus. Dual cables may be routed for standby redundancy. Loop back testing may also be achieved by connecting the transmit bus to the receive bus. The bus cable itself is practically unsaturating, being extremely broadband in nature (30 KHz to 1500 MHz). Channel assignments are presently being maintained in the 300 to 500 MHz portion of the band, each channel being 10 MHz wide. Line drivers can be added at strategic points along the bus to provide cable runs more than adequate to cover the entire airframe while maintaining the specified noise figure of the system.

The digital control bus is conveniently broken into two requirements. In one case digital data rates on the order of 10 Megabits must be transferred for receiver control parameters in processing spread spectrum type signals. There is also a need for a lower rate control bus on the order of 1 Megabit for all of the status and routine control requirements such as system initialization, FDM bus channel assignments and built-in-test. Ideally, separate channel assignments could be reserved on the wideband FDM bus for handling both the slow and fast digital control bus requirements.

Signal Conversion Subsystem

In the TIES context, there are two signal processors as shown in Figure 4. A distinction is made relative to the bandwidth requirements in each unit. Narrowband refers to signals less than about 300 KHz, wideband greater than 300 KHz. Under this definition the current TIES baseline calls for AM, FM SSB, Link 4, Link 11 and TTY waveforms to be handled in the NBSCU (Narrowband Signal Conversion Unit) and JTIDS, TACAN and IFF to be processed in the WBSCU (Wideband Signal Conversion Unit).

Each signal processor is under control of a remote microprocessor which receives instructions from the executive computer. The control system configures the processor as a modulator or demodulator for a particular waveform. Both signal conversion units interface to the receive and transmit FDM cables at a common 70 MHz IF frequency. The WBSCU must also interface directly to the Lx band frequency conversion subsystem to provide channelization assignments to the fast hopping synthesizers and direct AGC (Automatic Gain Control) to the IF amplifiers for certain types of waveforms. The baseband information is interfaced to the NBSCU and WBSCU through the device labled data processor in Figure 4. The data processors are used for bit formatting, error detection and correction, coding/decoding, and I/O interface functions.

The design philosophy in the TIES signal processing area is to pay the burden in cost and size for a set of programmable resources which can be time shared to process a variety of real time waveforms. Digital correlators, SAW (Surface Acoustic Wave) devices and CCD's (Charge Coupled Devices) are examples of the kinds of technology being employed in designing the signal conversion units. An implementation using a general purpose high speed digital processor has also been demonstrated for the Narrowband Signal Conversion Units.

HOW THE TIES ARCHITECTURE PROVIDES SPECIFIC ADVANTAGES

External and Built In Test (BIT)

In developing a system test philosophy for TIES, a distinction is made between external and built-in-test. External test is primarily an on the deck check out which requires the utilization of peripheral support equipment and typically gives more detailed information on system status. It might, for example, isolate a problem in the Lx band receive section to a faulty IF amplifier module which could then be replaced. Built in test gives an on-line operational readiness assessment of the system (GO/NO GO condition) and is completely self-contained. The criteria for passing BIT is predetermined and set at some minimum threshold level at strategic points throughout the system.

The TIES architecture allows an extremely powerful external test concept whereby every IF signal within the system can be accessed at one coax cable port on the FDM bus. The decoupling hardware used at the test port is exactly the same as that used within the system (OFF bus couplers). Standard test equipment can be used to receive signals on the receiver FDM cable, and to inject signals on the transmit FDM cable. Signals can be preprogrammed to execute standard test routines. The alternative is to produce a variety of unique support equipments for each set of CNI avionics on board the aircraft.

The Built-In-Test philosophy for TIES is dependent on a certain amount of overhead being paid for in test circuitry. This overhead takes the form of:

- (1) Pilot generators to provide test signals.
- (2) Status information being stored in remote microprocessors.
- (3) Initialization and control routines in the executive computer.
- (4) Fault detectors with appropriate interfacing hardware to the remote microprocessors.

BIT features are used primarily in-flight to provide on-line status and to achieve many useful fail-soft modes of operation.

In a typical scenario, the executive computer would periodically generate a command to initiate a test message throughout the transmit and receive paths. The message is completely wrapped around and received, then it is compared to what was sent. Acceptable signal levels are also present throughout the RF/IF signal path and monitored using peak detecting circuits. These peak detectors are used in conjunction with low cost Analog to Digital Convertors to send and store signal parameters in the remote microprocessors. The status information is always available to the operator through the executive controller to determine if the system is functioning according to some predetermined minimum performance criteria. Alerts can automatically be given to the operator and work around modes of operation can automatically be implemented to provide graceful degradation.

The FDM bus also provides a unique BIT feature inherent in the TIES architecture. Full connectivity can be established between any set of signal processing resources and RF resources. Thus, for example, on narrowband signal conversion unit can be set up as a modulator for some signal and set up on a specific channel assignment to talk to the other narrowband signal conversion unit which is set up as a demodulator. The roles of the two units can then be interchanged. This full loop back processing can be established among all IF signals in the system.

Reduced Logistics and Training Requirements

In the TIES architecture maximum effort is being put forth to develop a set of multi-function/multipurpose modules which can be shared for processing different waveforms in the same frequency band and in many cases across multiple frequency bands. As an example, the programmable 70 MHz IF amplifier which has been developed is used for the HF, VHF, UHF and Lx bands. The broadband VHF/UHF power amplifier has an extended frequency range from 30 to 400 MHz. Other examples can be found throughout the system. The net result is to greatly reduce the number of different spares which must be stocked and inventoried. Obviously, the non-recurring engineering cost is higher in developing a multipurpose programmable IF amplifier at 70 MHz than a designated piece of hardware but we feel that the long term payoff warrants this initial investment.

Training is simplified through the TIES architecture since the system consists of sets of standard modular resources all under control of a single system controller using one programming language and a standard I/O interface. In the conventional approach, each CNI function has unique control requirements, I/O interface, test routines and functional descriptions which must be learned. In addition, there is the added burden of operating the peculiar support equipment associated with each subsystem. The testing philosophy for TIES as previously discussed in the section on Built-In and External Test, establishes a common test routine for the entire CNI system.

Size and Weight Savings

The TIES architecture offers a significant size and weight saving over the conventional approach primarily for two reasons. First, because the FDM bus concept allows one to place RF hardware physically close to the antenna. As mentioned earlier, this results in a 3 to 5 db savings in cable loss, which translates directly into reducing prime power and reducing size and weight. Some basic calculations illustrating these savings are shown in Figure 6. It is interesting to note that in the TIES system there is a penalty paid for additional hardware such as the remote microprocessor and built-in-test circuitry which are part of the frequency conversion subsystem package. The price paid is reduced efficiency, nevertheless, the TIES architecture still offers a clear cut advantage in prime power savings.

The other architectural advantage which reduces size and weight is the elimination of redundant hardware through time sharing of the modular resources. A sizing of the platform operational requirements is done to determine simultaneous processing needs. In the Lx band, for example, if one realizes that a function like TACAN is needed only on operator demand and that an acceptable countdown level can be tolerated for IFF then the concept of using a common power amplifier and a common wideband signal processor for all the Lx band signals becomes very attractive. Separate control boxes are also eliminated by using a digital control bus which is managed by the platforms executive computer.

Flexibility and Growth Potential

One of the predominant problems in conventional system design is to achieve interoperability on a level appropriate to a particular platform need. Retrofit is out of the question for the TIES concept, however, the system design is flexible enough to allow a 1955 aircraft to talk to a projected 2005 aircraft. The carrier based ASW aircraft may require HF voice, HF data, UHF voice, TACAN, IFF and JTIDS. The command and control aircraft may require those functions plus VHF data and multiple HF, VHF, and Lx band channels. Both aircraft can be accommodated within the TIES architecture using the FDM bus design and the number of standard modular elements peculiar to the need. The software control, BIT and external test is modular in both cases and is merely loaded with the proper input variables to handle either need. The narrowband and wideband signal conversion units are functionally programmable and can serve both requirements. Early obsolescence is eliminated since the addition of new functions or the need for enhanced capability can be addressed on a modular basis rather than a total system redesign.

PROGRAM STATUS AND ACCOMPLISHMENTS

The TIES program is being sponsored by the Naval Air Systems Command (AIR-360) with the Naval Air Development Center acting as the lead laboratory. Efforts are on-going in the exploratory development phase with the transition to advanced development (ADM phase) scheduled to begin in 1979. A baseline TIES system, similar to that shown in Figure 4, is being integrated into the TIES laboratory at NAVAIRDEVCON. This lab integration will culminate in a full-up TIES feasibility demonstration in early 1980.

The system currently being developed and tested is based on a series of earlier study contracts which defined the system architecture and signal processing requirements. Basic design concepts have also been studied and documented in the digital multiplex area, the frequency division multiplex area, the RF, and control subsystem areas. Some of the major

modular developments which have been completed and provide a firm foundation for the system architecture and design goals will be discussed. Ultimately, it is this technology base that is the key as to whether or not TIES will be a viable system concept for our next generation military aircraft.

1 Kilowatt Lx Band Solid State Amplifier

A solid state 1 Kw power amplifier has been constructed and tested using a 250 watt 10% duty cycle transistor as the basic building block. The amplifier is broadband (960-1215 MHz), requires no tuning, and will satisfy the requirements for JTIDS, TACAN, or IFF signals. The drive level required is 50 watts. Its size is approximately 9.5 x 4.5 x 1 inch. The transistor contractor is Power Hybrids Incorporated.

Fast Hopping Lx Band Synthesizer

This fast hopping indirect frequency synthesizer provides the LO injection for receivers used for JTIDS and TACAN. It operates from 1025-1150 MHz, switches in 1 MHz steps and settles anywhere within the band in 13 microseconds to 6 KHz of the selected frequency. The power output is +17 dBm and the input power required is 10 watts. The size of the brassband model is 10 x 10 x 10 centimeters. The contractor is ZETA Laboratories.

Lx Band Receiver Front End

The front end receiver is used to receive JTIDS, TACAN, and IFF signals and covers the Lx Band from 960 to 1215 MHz. The fast hopping frequency synthesizer is used as the local oscillator. High and low side injection is used to convert the Lx band down to a standard 70 MHz IF frequency. The receiver uses two and five pole varactor tuned filters which are controlled by an 8 bit control word. The 3 dB bandwidth of the filters is approximately 18 MHz. Size is approximately 10 x 10 x 2 centimeters. The contractor is ZETA Laboratories.

Programmable IF Amplifier

This amplifier module is designed to provide the proper gain, filtering and transfer characteristic for the signal being received via programmable control. The module which has been built has a 70 MHz center frequency and is capable of log, linear, or limiting performance with either fast or slow AGC. The gain of a single module is 25 dB. The brassboard size is approximately 12 x 4 x 3 centimeters. The contractor is ZETA Laboratories.

Programmable IF Filter

The IF filter module is a programmable surface wave device which also has a 70 MHz center frequency. It can be programmed to any one of four bandwidths; 30 KHz, 70 KHz, 350 KHz or 7 MHz at the 3 dB points with a 3/1 shape factor. Its size is approximately 2 x 3 x 0.5 inches. The contractor is Teledyne Incorporated.

Broadband RF Power Amplifier (2-400 MHz)

The objective of this development program was to develop a 30 dB gain single broadband amplifier chain with an AM carrier output power capability of 12.5 watts from 118 to 400 MHz, an FM carrier output of 15 watts minimum from 30 MHz to 400 MHz and linear operation for single sideband operation in the 2 to 30 MHz frequency range. A high level modulation capability for the amplifier chain is also provided in each mode of operation. The efficiency of the amplifier is 50% minimum from 30 to 400 MHz. A brassband model of the amplifier consisting of a pre-driver, driver, and power amplifier has been fabricated and delivered to NAVAIRDEVCON and is meeting these design goals. A miniturization program will follow. The contractor is Power Hybrids Incorporated.

On-Off Bus Coupler

The On-Off Bus Coupler is part of the standard interface which is capable of converting the 70 MHz IF frequency to any frequency from 300 MHz to 500 MHz. The coupler is operable from 50 KHz to 1 GHz with 0.5 dB insertion loss. The excess bandwidth can be used for adding additional signals not included in the basic CNI requirements such as audio or video distribution. The size of the coupler is approximately 1 x 1 x 0.7 inches exclusive of the synthesizer used for the frequency conversion. The contractor is Mini Circuits Laboratory.

Narrowband Signal Conversion Unit

A TIES brassboard Narrowband Signal Conversion Unit has been completed and is currently being tested and integrated. The processor uses 2900 series microprocessor components for implementation of recursive digital filters in a multiplexed sampling scheme to provide simultaneous processing of three channels in any combination, transmit or receive, for AM, FM, single sideband and FSK modulated signals. The unit can also be programmed to provide a single wideband processing capability (48 KHz). An 8080 microprocessor provides man machine interface (via R5-232 channel) for initialization, mode selection, and loading of parameters for the digital processing section. The contractor for the NBSCU is General Dynamics Corporation, San Diego, California.

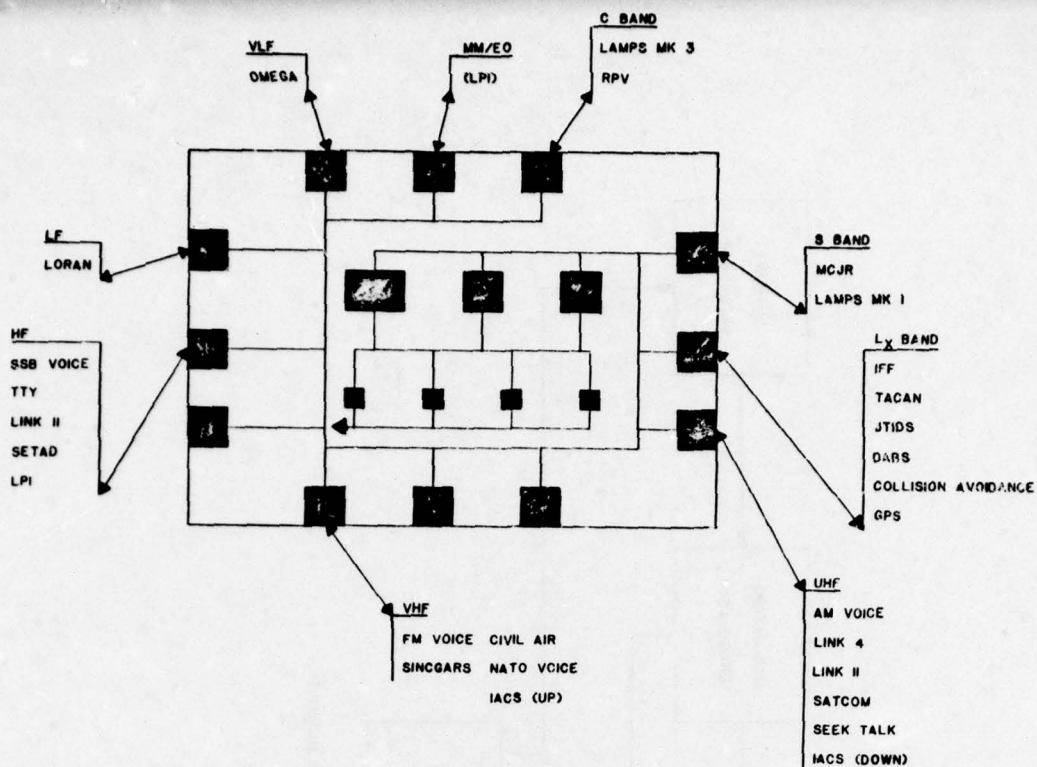


Fig.1 TIES RF environment

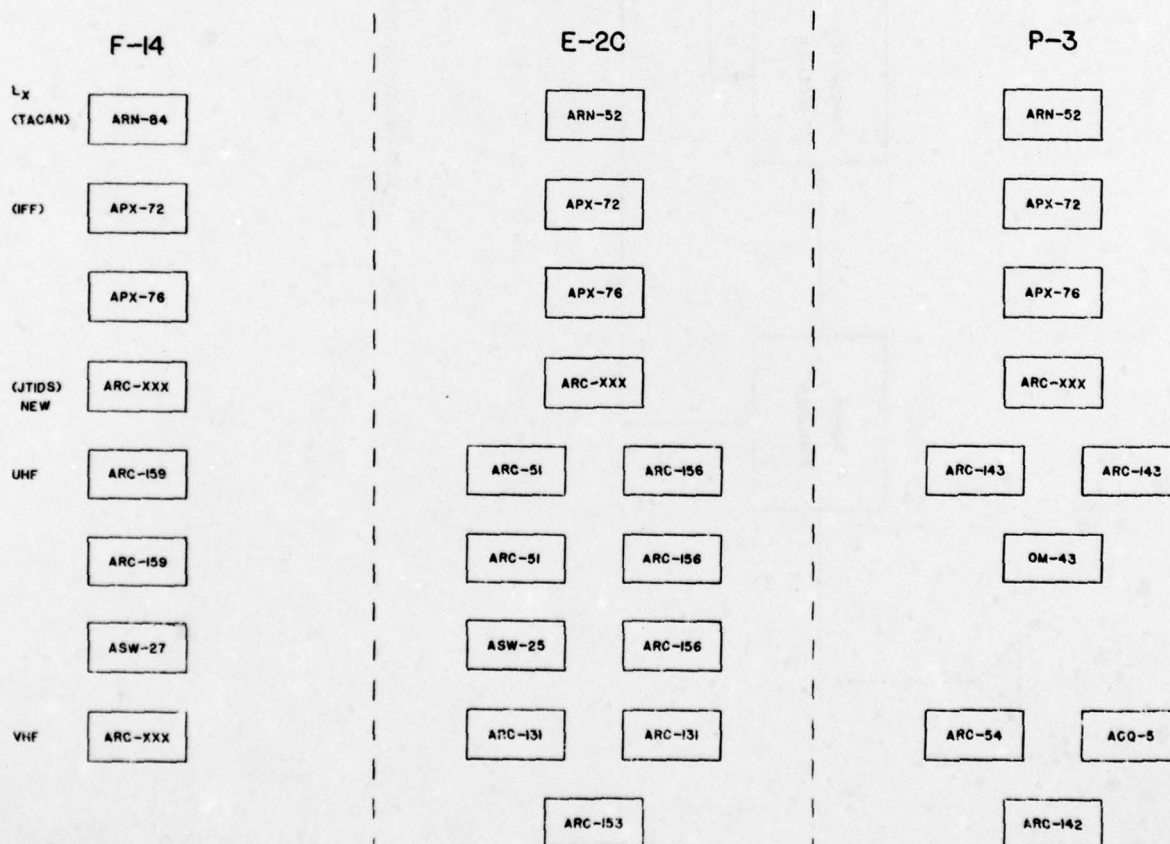


Fig.2 Customized "Black Box" avionics

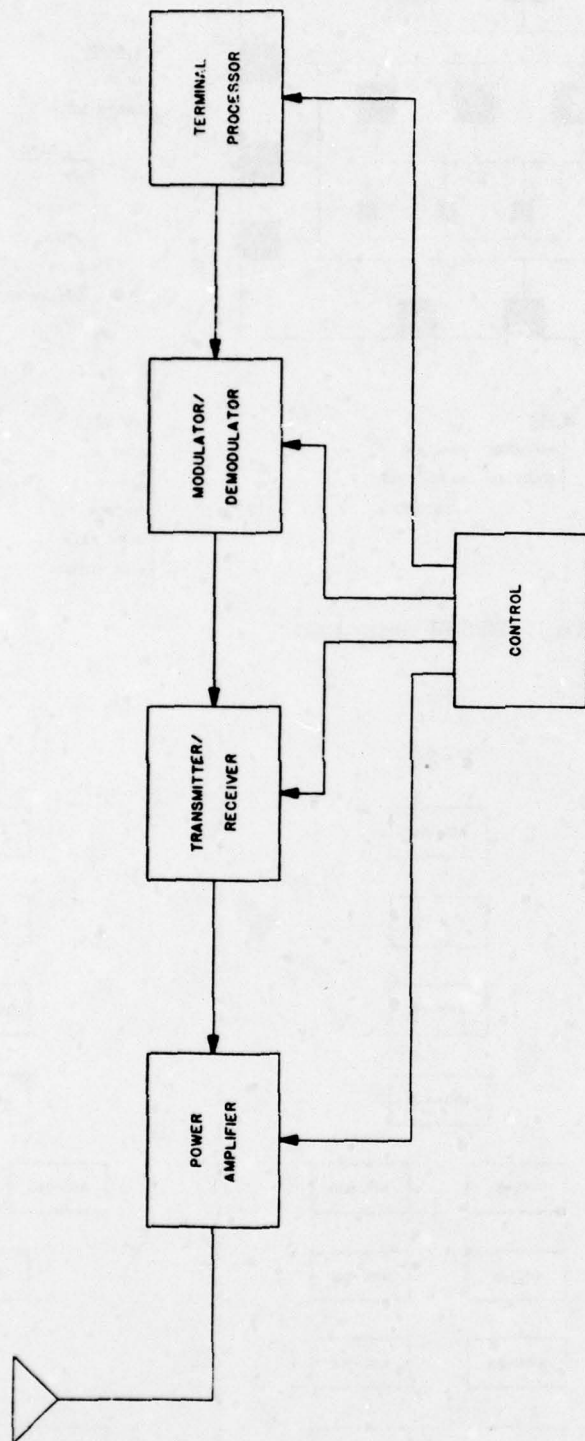


Fig.3 Typical communications system block diagram

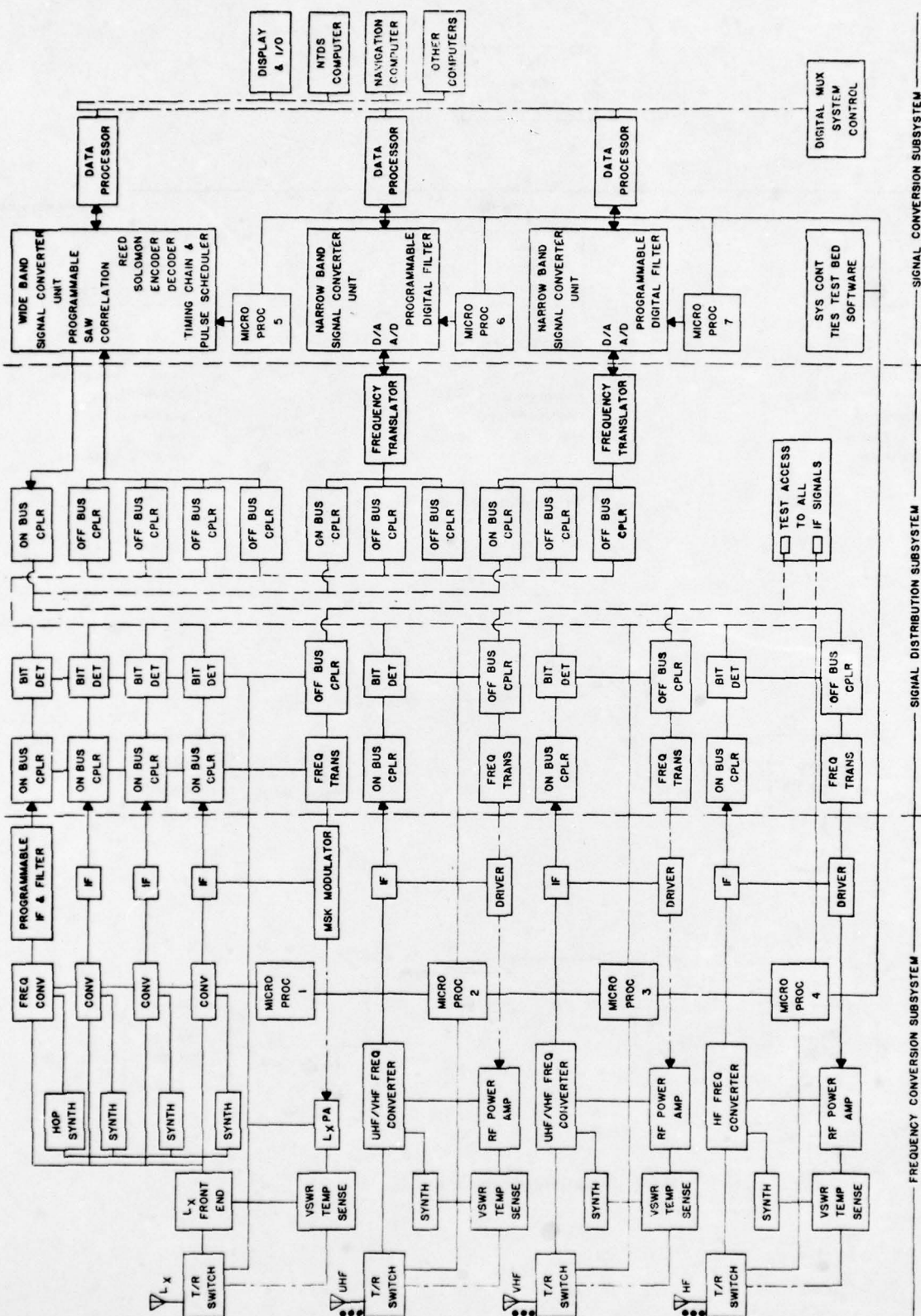


Fig. 4 TIES system block diagram

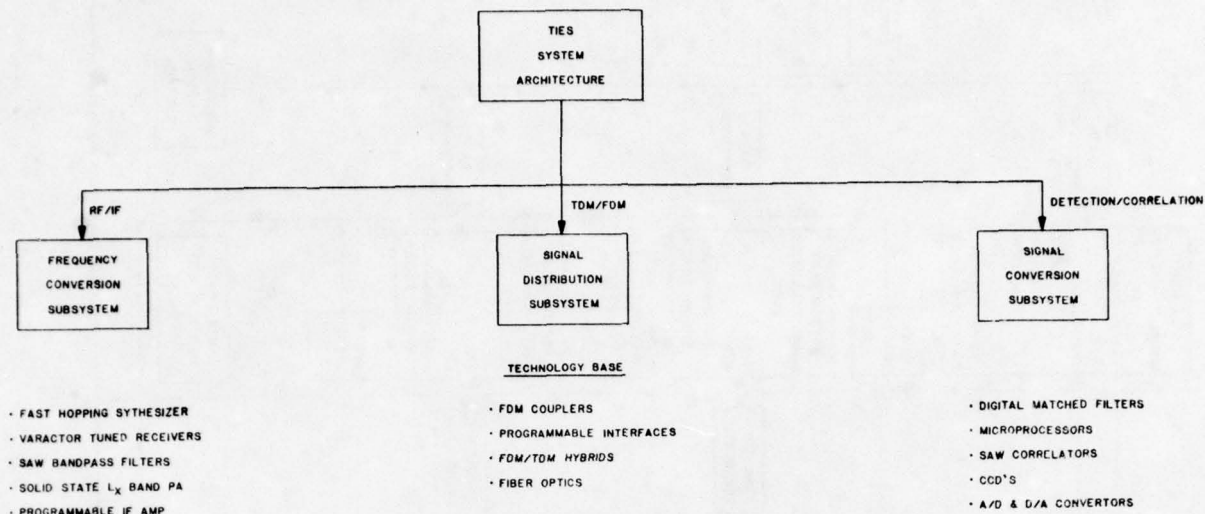
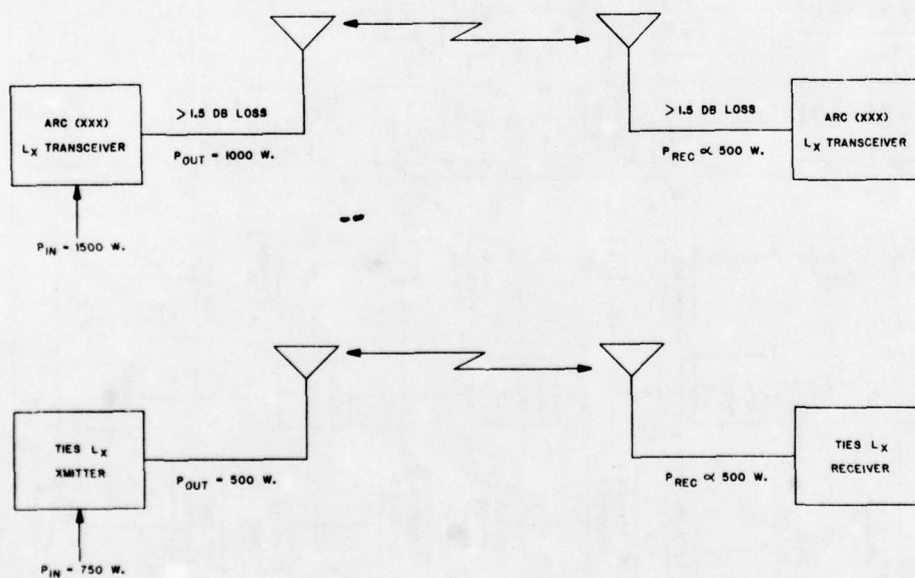



Fig. 5 TIES subsystem partitioning

Fig. 6 Prime power comparison (L_X Band)

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14. Abstract			
<p>Consists of the papers and discussions presented at the Avionics Panel Meeting on the subject, in Monterey, California, 18-21 October 1978. Thirty-two papers apportioned as follows: two on operational requirements; six on data acquisition, display and control; six on communications; four on tactical data processing hardware; six on applications programming; and eight on tactical systems.</p>			

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